Technical Abstracts

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7660-01, Session 1

Simulator of IRST system with ATR embedded functions

B. Sozzi, G. Barani, N. Santini, E. Fossati, A. Ondini, G. Colombi, C. Quaranta, SELEX GALILEO (Italy)

This paper presents a soft-real time simulator of IRST (InfraRed Search and Track) systems with ATR (Automatic Target Recognition) embedded functions to test performance airborne applications. The IR camera model includes detector, optics, available Field-of-Regard, etc., and it is integrated with the motion platform local stabilization system to consider all factors impacting IR images. The atmosphere contributions are taken into account by means of a link to ModTran computer program. Sensor simulation allows derivation and assessment of IR Figures of Merit (NEI, NETD, SNR...). IR signatures of targets derive both from data collected in specific trial campaigns and from laboratory built models. The simulation of the scan procedure takes into account different policies (ground points paths or defined angular volume) and different platform motion strategies (continuous or step steering scan). The scan process includes Interacting Multiple Model (IMM) technique to face unexpected variations of aircraft motion. Track and ATR processors are simulated and run consistently on the output of the sensor model. The simulator functions are developed in MatLab and SIMULINK and then exported in C code to be integrated in soft real-time environment.

The use of this simulator supports the definition and design of the IRST systems especially for the evaluation of the most demanding operative requirements. An application of this simulator is in the NEURON UCAV (Unmanned Combat Air Vehicle) technological demonstrator, which accommodates on board both IRST and ATR tasks.

7660-02, Session 1

New generation of naval IRST: example of EOMS NG

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Nowadays, Naval Combat Systems (NCS) have to deal with different kinds of threats including air targets and surface targets such as missiles and warships. Plus, current asymmetric targets such as fast moving rubber boats for suicide actions have to be taken into account. Eventually, modern warship missions have to cope with "blue" and "brown" water missions e.g. backgrounds including sea, sky but also coastal lands observed at very short range.

Connected to the NCS, IRST systems provide Contact Reports located in angles while being fully covert. Of course, they have to detect, lock-on, track and classify multiple threats on various backgrounds and atmospheric conditions.

In this paper, an application of new IRST generation at sea is described. The EOMS NG from SAGEM is presented. More precisely, the article is divided into three parts. The first part puts forward the requirements of the new IRST generation in terms of scenarios to deal with. They combine classic targets and new asymmetric ones. Background requirements have also evolved during the last decade linked directly to new missions. In the second part, the system architecture of EOMS NG is described including Image & Tracking Processes. They are challenging by providing as soon as possible accurate Target Indications to NCS according to Lock-on time requirements while having very low false alarms rates in heavy clutter (solar glint...).

In the last part, system performances are given for different scenarios provided from Field Tests. Data include different targets, backgrounds and illumination conditions. The results highlight the impact of the new processes in the overall system reaction time even in drastic conditions.

7660-03, Session 1

Performance characteristics of a submarine panoramic infrared imaging sensor

J. R. Waterman, K. P. Judd, J. M. Nichols, U.S. Naval Research Lab. (United States); J. W. Devitt, L-3 Communications Cincinnati Electronics (United States); R. Menon, RemoteReality Corp. (United States); R. Smith, Smart Logic Inc. (United States)

This work reports on the radiometric and imaging performance characteristics of a passive mid-wave infrared panoramic imaging sensor. The sensor includes an f/2.5 catadioptric optical system that provides a 360 degree azimuth by -10 to +30 degree elevation field of view. The focal plane is a 2,000 x 2,000 15 micron pitch InSb detector operating at 80K. The measured radiometric performance, including NEDT and NEI, of the integrated system will be presented and compared with modeling based on stand-alone focal plane and optics characteristics. The dependence of NEDT on background flux and integration time will be discussed. The measured system MTF will be presented and compared to theoretical predictions based on modeling of the focal plane and optical system. The thermal characteristics of the sensor and its performance under stressing environmental conditions will be presented. The implementation of the real-time image processing system for un-warping and display of the panoramic scene will be described. This PCI hosted FPGA approach provides full field of view 30 Hz video at the native sensor resolution as well as full resolution virtual pan-tilt-zoom region-of-interest views and JPEG2000 compressed video for network dissemination. Sample imagery from laboratory and maritime environments will be shown.

7660-04, Session 1

ARTEMIS: first naval staring IRST in service

J. L. Fontanella, D. Delacourt, V. Megaides, Thales Optronique S.A. (France)

Dealing with military and asymmetric threats represents a key issue for any military vessel in various environment. In order to support ship's self protection, Thales has designed a new generation of naval infrared search and track (IRST) called ARTEMIS. It has been selected to equip Future European Multi Roles Frigates (FREMM).

ARTEMIS is a fully passive staring IRST system capable of automatically detecting and tracking both air and surface targets simultaneously. It is able to detect and track maneuvering and stealthy new threats as well as surface asymmetric threats.

The paper describes the novelties of the ARTEMIS staring architecture and its technologies. It describes also the advantages offered by this new concept of electro-optical surveillance with full static sensor heads compared to existing and futures solutions, and its capabilities to comply with future integrated masts standards.

The paper concludes by a presentation of the in service product for the French Navy.

7660-05, Session 1

SASS: a bi-spectral panoramic IRST - results from measurement campaigns with the Italian Navy

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This paper presents SASS (Silent Acquisition and Surveillance System), the new Infrared Search and Track (IRST) system developed for the Italian Navy. SASS is designed and developed for automatic multiple target tracking of ship threats (fighter aircraft, missile, small boat,...), providing operators with visual panoramic surveillance and navigation-aid capabilities too, by means of real time panoramic view. Two SASS models have been developed: monospectral and bispectral, operating in the mid-wave and long-wave infrared bands. The usage of the two IR bands halves input measurement errors and allows better performance in terms of high detection probability, reduced number of false tracks and short time for track declaration. The monospectral version has been tested on a Maestrale class frigate in real operative scenarios. The bispectral version has been tested at Navy support and testing facilities and installed on the Italian aircraft carrier "Cavour". Some measurement campaigns have been performed to test tracking system performances. Elaborate field trials with the intention of simulating operative conditions have been carried out at Navy site in Livorno: relevant naval and airborne units were used to test the system against different kinds of targets (ship, helicopter, etc.). Further test sessions have been performed on board the "Cavour" aircraft carrier, involving both sea and air targets. Comparative results including different environmental conditions and different test configurations are presented.

SASS has been selected for the Italian future European Multi Mission Frigates (FREMM).

7660-06, Session 1

Passive shortwave infrared technology and hyperspectral imaging for maritime applications

K. P. Judd, J. R. Waterman, U.S. Naval Research Lab. (United States)

We present image data and discuss naval sensing applications of SWIR and Hyperspectral SWIR imaging in littoral and marine environments under various light conditions. These environments prove to be challenging for persistent surveillance applications as light levels may vary over several orders of magnitude within and from scene to scene, imaging over long water paths where marine haze and turbulence tend to degrade radiation transmission, and discrimination of low contrast objects under low-light and night imaging. Image data obtained from two separate passive sensor systems, both of which are built around an RVS large format (1280 x 1024) InGaAs FPA with high dynamic range and low noise electronics, are presented. The SWIR camera imager is equipped with a custom 300 mm focal length f/2 narrow field-of-view (6° diagonal) refractive telescope. The Hyperspectral imager has a custom selectable 900/1800 mm focal length telescope with corresponding 1.55°/0.79° field-of-view and f-numbers of 3/6 respectively. The sensor uses 1280 pixels in the spatial direction and a window of 192 are used for the spectral and operates at a nominal frame rate of 120 Hz. To assess field performance of the SWIR/Hyperspectral imagers, comparison is made to output from a scientific grade VNIR camera and two state-of-the-art low-light sensors.

7660-07, Session 2

Innovative optronics for the new PUMA tank

M. O. Münzberg, J. Fritze, H. H. Schlemmer, Carl Zeiss Optronics GmbH (Germany)

The new PUMA tank is equipped with a fully stabilized 360° periscope with different magnification stages. The motion of the hull relative to the turret is compensated by an innovative joined direct optical channel in the center of the turret. It provides a direct optical view either to the commander or to the gunner. The periscope contains a cooled thermal imager and a visible camera to provide a digital image parallel to the direct view optical channel. The fully optronical stabilized gunner sight is coaxial mounted to the main gun and is equipped with a visible camera,

a cooled thermal imager and a laser range finder. All optronical images can be feeded on every electronic display within the vehicle. In addition the thermal image can be displayed on an OLED inside the direct view optical channel. The PUMA has hunter - killer capability by transmitting the view of the commander to the gunner sight. The thermal imager in the periscope and the gunner sight is identical. It operates with a long wave 384x288 MCT starring focal plane array cooled with a small integral cooler. The high quantum efficiency of MCT provides very low NETD values at very short integration times. The thermal imager has an image resolution of 768x576 pixels by means of a 2x2 microscanner. The MCT detector operates at high temperatures above 75K with high stability in noise and correctibility and offers high reliability (MTTF) values for the complete camera in a very compact design. The paper discusses the principle and functionality of the optronical combination of direct view optical channel, thermal imager and daysight camera and discusses in detail the demands on the subcomponents in respect of performances for new tank applications.

7660-08, Session 2

Mid-wave infrared (MWIR) panoramic sensor for various applications

C. A. Bjork, Jr., W. H. Wan, Lockheed Martin Coherent Technologies (United States)

The paper describes a Mid-wave Infrared (MWIR) Panoramic Sensor using existing focal plane array (FPA) technologies and commercially available IR optics, and packaged in a relatively simple and rugged manner to provide a 360-deg azimuth and 60-deg elevation field-of-view coverage, without any scanning mirror. This sensor can be deployed for initial target tracking, situational awareness, perimeter security, and other applications. The basic performance and parameters of the Sensor, such as mechanical, electrical interfaces, optical parameters, etc. are also included. Some basic sensor performance analysis (such as target signal-to-noise ratio verses range and background level), and field testing results are also presented and compared for some simple levels of processing.

7660-09, Session 2

A low-power XGA thermal camera for ground applications

S. Kummer, L-3 Communications Infrared Products (United States)

The advent of uncooled, XGA (1024-768) focal plane arrays enables new applications for ground vehicles and equipment. A low-power digital imaging module, based on a 17μm-ptich FPA, has been developed and packaged in a rugged housing for demonstration in a distributed aperture system. The camera can extend the performance of existing uncooled vehicle-deployed systems and offer a potential replacement for cooled sensors in some applications.

7660-150, Session 2

Novel multi-camera thermal imaging method and apparatus

G. J. Kemeny, G. A. Groth, N. A. Crothers, Middleton Research (United States)

Thermal imaging developments are producing increasingly better spatial resolution using larger focal plane arrays and differentiation of ever smaller temperature differences using improved detector arrays. Thermal cameras with higher resolution and cameras with cooled MCT or InSb focal plane arrays offer improvements in resolution and thermal differentiation, respectively.

A third direction for continued development is spectral differentiation within the wavelength range of thermal cameras. Cameras with rotating filters record multiple wavelength images through a process of splitting the available measurement time and consecutively recording images with different wavelengths. Continuous wavelength hyperspectral cameras on the other hand, produce a complete spectrum or portion of the infrared spectra for each spatial point at the same time, however, only one line at a time, or one wavelength at a time.

Another direction in thermal imaging involves multi-camera systems that offer improvements in other "dimensions" by enabling independent information to be gained by the individual cameras. Some of these improvements are: simultaneous multi-wavelength measurements, multiple dynamic range measurements and improved appearance of the image beyond the one-dimensional temperature scale coloring schemes. Advantages and functions of dual camera imaging will be presented. Potential future extensions as well as limitations of the current designs will be discussed.

7660-11, Session 3

A night sight clip on module based on uncooled infrared detector technology as one part of a modular equipment for the well-armed soldier

B. H. Ledertheil, C. Berlips, Carl Zeiss Optronics Wetzlar GmbH (Germany); M. O. Münzberg, Carl Zeiss Optronics GmbH (Germany)

The night sight clip on module based on uncooled infrared detector technology was designed around an infrared camera module. This camera module uses an uncooled 640 x 480 detector and has a highly integrated electronic.

The night sight clip on module has a magnification of exactly one and a precisely prealigned line of sight with respect input to output. The module is designed to be used in front of a standard day sight telescopic aiming optic on an assault rifle. The sophisticated optical design of the clip on module eliminates the need of a realignment of the day sight optic when the module is placed in front of it. Also there is no need for a precise placement or angular alignment of the module in front of the day sight aiming telescope.

The signal of the IR camera is displayed on a small monitor. This picture is then collimated to infinity and used as the input for the daysight telescope. The rifleman sees in the eyepiece of his telescopic daysight an infrared image of the scene. The magnification is done by the setting of his telescope. The aiming reticle is still the one from the day scope.

The optical design of the night sight clip on module and the electronic block diagram will be presented.

7660-12, Session 3

A high-performance clip on thermal sight for combat rifle scopes

S. P. Way, N. Jolivet, J. Hansen, FLIR Systems, Inc. (United States); D. Schick, T. Maciak, Trijicon, Inc. (United States)

The Trijicon ATWS is a high performance, lightweight, compact clip on thermal sight for use with the TA31RCO ACOG weapon sight. FLIR systems partnered with Trijicon to develop this sight using the photon 640 imaging core. This paper will discuss the features and performance of the ATWS and describe some of the design challenges associated with this type of device. This paper will discuss optical design, materials selection and the design for high shock environments. Methods and Equipment used for reliability testing will be discussed.

7660-13, Session 3

Uncooled IR sensor technology for hostile fire indication systems

S. Nadav, M. Zahler, M. Danino, G. Brodetzki, Elisra Electronic Systems Ltd. (Israel); R. Schlisselberg, Ministry of Defense (Israel)

Evolving combat arena poses an ever growing hostile fire threats for various ground and airborne targets. Protecting both static and moving miltary assets against these threats requires both high performance and affordable solutions, favoring uncooled sensing alert technologies. By analyzing accumulated target and clutter data using new algorithmic and hardware building blocks we establish improved HFI system configurations. The paper will review new system demonstrations harnessing uncooled IR sensors technology alongside empirical field testing results.

7660-14, Session 3

HgCdTe position sensitive detector development

E. P. Smith, E. J. Beuville, G. M. Venzor, Raytheon Co. (United States); R. Wolfshagen, M. K. Wilcox, B. Scott, Oceanit Labs., Inc. (United States)

Raytheon Vision Systems (RVS) is collaborating with Oceanit Laboratories Inc. to develop a novel HgCdTe-based position sensitive detector (PSD) that can ultimately be implemented in Target Detection and Tracking or Target Interception Applications in the infrared spectral region. In order to realize advanced HgCdTe PSD designs, the ability to operate the device via four contacts per unit-cell and independently control and optimize both the resistance of the metal-semiconductor contacts and the sheet layer resistance between the contacts is desired. The RVS development approach for 250 μm to 500μm unit-cell HgCdTe PSD detectors is based on the use of molecular beam epitaxy (MBE) material growth on 4-inch Si wafers with a p-on-n double layer heterojunction (DLHJ) device architecture and implementation of multiple inductively coupled plasma (ICP) etching process steps during device fabrication. Experimental variations for both the detector design and fabrication processes have been evaluated to optimize the performance of HgCdTe PSD detectors developed at RVS. This paper will review and explain the details of PSD detector operation and report on HgCdTe PSD detector characterization associated with the experimental variations implemented in detector design, MBE growth, and detector fabrication.

7660-16, Session 4

Parameterized nonuniformity corrections for non-temperature stabilized InGaAs SWIR sensing

J. Battaglia, Sensors Unlimited, Inc., part of Goodrich Corp. (United States); V. Burzi, Process Automation Corp. (United States); B. Moyer, T. Sudol, Sensors Unlimited, Inc., part of Goodrich Corp. (United States)

Because of its ability to exploit major untapped windows of atmospheric transparency in the infrared, the defense community has recognized the SWIR band as an effective method of day/night passive imaging.

Military applications for conventional InGaAs SWIR sensing have been limited by the requirement of thermo-electric cooler (TEC) temperature stabilization for non-uniformity correction (NUC) of dark current and response non-uniformity. TEC operation restricts the operating temperature range, requires significant power for temperature stabilization at high and low ambient temperatures, and necessitates bulkier hermetic packaging techniques. For battery-powered man portable and micro UAV applications, increasing operating temperature

range while reducing size, weight, and power (SWAP) are critical.

This paper discusses the advantages of our non-TEC temperature parameterized NUC corrections algorithms versus TEC stabilized architectures. The corrections algorithms enable arbitrary polynomial order correction of both pixel uniformity and temperature parameterization. The algorithm can be driven by corrected NUC performance criteria, hardware memory limitations, or both. Other features include dynamic coefficient and memory allocation by sensitivity analysis for different operating temperature ranges, exposure times, and gain settings, and the ability to simulate different corrections schemes on arbitrary images before instantiation in hardware.

In combination with the improved response uniformity of our CTIA pixel designs, parameterized NUCs enable wider operating temperature ranges, lower power, and non-hermetic chip-on-board type packaging technologies. These advances enable SWIR InGaAs sensing to meet the SWAP requirements of next generation military applications.

7660-17, Session 4

InGaAs SWIR sensors for low-light level sensing with and without illumination

M. H. MacDougal, J. Geske, C. Wang, Aerius Photonics, LLC (United States)

Aerius Photonics specializes in low dark current, high operability large InGaAs detector arrays. Aerius will present characterization data from FPAs made using their detector arrays. In particular, the dark current data will be shown at different temperatures, and the photon transfer curve. The dark current data will show that Aerius is achieving better than 3 nA/cm2 at 20°C. The photon transfer curve will show that the read noise on these devices is less than 60 electrons. In addition, Aerius will show imagery under different conditions including low light as well as daytime imagery. The imagery will include images taken with and without external illumination. Aerius has developed VCSEL arrays that provide flat illumination in scenes with no available photons. Unlike other laser-based illuminators, Aerius illuminators do not show coherence or speckle. Aerius will show imagery from their FPA using the illuminators. The illuminators are based on lasers that have efficiencies greater than 40%, enabling their use in power-constrained situations.

7660-18, Session 4

SiGe-detector arrays for visible-NIR imaging sensor applications

A. K. Sood, R. A. Richwine, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); N. DiLello, J. L. Hoyt, Massachusetts Institute of Technology (United States); C. C. Li, DRS Technologies, Inc. (United States); S. B. Horn, Defense Advanced Research Projects Agency (United States); R. S. Balcerak, Raymond S. Balcerak LLC (United States); T. G. Bramhall, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States)

SiGe based focal plane arrays offer a low cost alternative for developing visible- near-infrared focal plane arrays that will cover the spectral band from 0.4 to 1.6 microns. The attractive features of SiGe based foal plane arrays take advantage of silicon based technology that promises small feature size, low dark current and compatibility with the low power silicon CMOS circuits for signal processing. This paper will discuss performance characteristics for the SiGe based VIS-NIR Sensors for a variety of defense and commercial applications using small unit cell size and compare performance with InGaAs, InSb, and HgCdTe IRFPA's. We will present results on the approach and device design for reducing the dark current in SiGe detector arrays. We will discuss electrical and optical properties of SiGe arrays at room temperature and as a function of temperature. We will also discuss future integration path for SiGe devices with Si-MEMS Bolometers.

7660-19, Session 4

Wide-band imaging for enhanced day and night vision

C. S. Rafferty, B. Ackland, C. A. King, J. Y. Sproul, I. Aberg, J. H. Oneill, T. S. Sriram, C. Godek, A. Lattes, S. H. Pappas, A. Buck, V. Jovanovic, NoblePeak Vision Corp. (United States)

Visible-band cameras using silicon imagers provide excellent video under daylight conditions, but become blind at night. The night sky provides illumination from 1-2 µm which cannot be detected with a silicon sensor. Adding short-wave infrared detectors to a CMOS imager would enable a camera which can be used day or night.

A germanium-enhanced CMOS imager (TriWave) has been developed with broadband sensitivity from 0.4 µm to 1.6 µm. A 744 x 576 format imager with 10 µm pixel pitch provides a large field of view without incurring a size and weight penalty in the optics. The small pixel size is achieved by integrating a germanium detector into a mainstream CMOS process. A sensitive analog signal chain provides a noise floor of 7 electrons. Hundreds of VGA-format imagers are fabricated on each 200 mm wafer, allowing performance characterization at wafer probe. The imagers are hermetically packaged with a thermo-electric cooler in a windowed metal package of volume 5 cm3. A compact (<650 cm3) camera core has been designed around the imager. Camera functions implemented include correlated double sampling, dark frame subtraction and non-uniformity corrections.

In field tests, videos recorded with different filters in daylight show useful fog and haze penetration over long distances. Under clear moonless conditions, SWIR images recorded with TriWave make visible individuals that are invisible in videos recorded simultaneously using an EMCCD. Band-filtered videos confirm that the detected illumination is dominated by wavelengths above 1200 nm.

7660-20, Session 4

Black silicon enhanced photodetectors: a path to IR CMOS

M. U. Pralle, J. E. Carey, SiOnyx Inc. (United States)

SiOnyx has developed a next generation silicon based photodetector with spectral sensitivity from 350 to 1300 nm. By doping silicon with sulfur using femtosecond laser processing, we enhance the spectral sensitivity of silicon enabling high performance infrared detection on a CMOS compatible chip well beyond the bandgap cutoff of traditional silicon. These detectors exhibit enhanced QE, photoconductive gain, (with responsivities in excess of 100 A/W) and compelling low noise performance. Absolute noise characterization coupled with spectral responsivity characterization indicate measured detectivity (D*) of $1x10^{14}$ Jones at 940nm, roughly a factor of 10 higher than the best silicon photodetectors. Operating at mere 3V these devices rival avalanche photodiodes at much lower power and bias. When applied to imaging platforms, this detector will enhance visible light imaging and will enable silicon to become the next generation nightvision detector, outperforming incumbent technologies in nearly all nighttime light conditions.

7660-21, Session 4

High-performance low-power CMOS image sensor for digitally fused night vision systems

B. Fowler, P. Vu, C. Liu, S. W. Mims, W. Li, H. Do, J. Appelbaum, Fairchild Imaging (United States)

We present the performance of a recently developed low power 1600(H) x 1200(V) CMOS image sensor optimized for next generation fused night vision systems. This all solid state night vision sensor features small size, low weight, low power dissipation and high performance without

multiplicative noise. In addition, the sensor has 5T pixels with pinned photodiodes on a 6.5µm pitch with integrated micro-lens. The 5T pixel architecture enables both correlated double sampling (CDS) and a lateral anti-blooming drain. The measured peak quantum efficiency of the sensor is greater than 60% at 600nm, and the read noise is less than 1e- RMS at room temperature. The sensor features dual gain 11-bit data output ports and supports 30 fps and 60 fps operation. At 30 fps, the power consumption is approximately 320 mW with both output ports operating and less than 210 mW with a single output port (low gain). The full well capacity is greater than 30ke-, the dark current is less than 3.8pA/cm2 at 20ºC, and the MTF at 77 lp/mm is 0.4 at 600nm. The sensors limiting resolution is greater than 10 lp/mm with clear starlight illumination. The sensor also achieves an intra-scene linear dynamic range of greater than 90dB (30000:1) and an inter-scene dynamic range greater than 140dB (10,000,000:1), making it idea for both day and night applications. The sensor measures approximately 13 mm (H) x 15.4 mm (V), and weighs less than 1 gram.

7660-22, Session 4

Hybrid infrared optical upconverting devices with a built-in electrical gain

J. Chen, D. Ban, Univ. of Waterloo (Canada); M. Helander, Z. Lu, Univ. of Toronto (Canada); P. J. Poole, H. C. Liu, National Research Council Canada (Canada)

An optical upconverter converts light from a longer wavelength to a shorter wavelength. The near infrared optical upconverters in the eye-safe region around 1.5 micrometer are of particular interest because of their many potential applications such as night vision, active surveillance and homeland security. Hetero-integration of organic materials with inorganic functional substrates has been proposed and demonstrated to fabricate near infrared (NIR) hybrid organic/inorganic optical upconverters [1, 2], which were made by direct tandem integration of an inorganic InGaAs-InP photodetector (PD) with an organic light-emitting diode (OLDE). As each constituent organic molecule is topologically a perfect structure, the growth of each organic layer does not require "lattice matching", leading to an unprecedented freedom on the selection of various substrates for the integrated devices. However, the external efficiency of the hybrid upconversion device has yet to be improved. In this talk, I will report the recent progress of our research groups on design and fabrication of new-structure organic/inorganic hybrid optical upconversion devices that converts light from 1.5 micrometer to 520-545 nm. We have adopted new strategies to improve the external device efficiency, including insertion of an embedded mirror and integration of a heterojunction phototransistor (HPT) and an OLED. As a result, infrared optical upconversion is demonstrated at room temperature with a built-in electrical gain of 15 from the HPT and an external upconversion efficiency that is improved by one order of magnitude.

[1] Dayan Ban, et. al., Appl. Phys. Lett., Vol. 90, (2007) 093108.

[2] Jun Chen, et. al., J. Appl. Phys. Vol. 103, (2008) 103112.

7660-23, Session 4

SWIR HgCdTe HDVIP detectors MTF Monte Carlo modeling and data

A. I. D'Souza, D. Stapelbroek, C. Yoneyama, P. Ely, M. R. Skokan, H. Shih, DRS Sensors & Targeting Systems, Inc. (United States)

The Monte Carlo modeling simulates minority carrier diffusion from carrier creation to recombination. Each carrier generated at an appropriately-weighted random location is assigned an exponentially-distributed random lifetime ti where is the bulk minority carrier lifetime. The minority carrier is allowed to diffuse for a short time dt such that the mean is zero and the variance is 2*Dcoeff*dt in each dimension, where Dcoeff is the diffusion coefficient of minority carriers. The time lived is incremented by dt and the fate of the carrier is decided from its present position and the boundary conditions, i.e. is the carrier absorbed in a junction,

recombined at a surface, reflected from a surface, or recombined in the bulk because it lived for its designated lifetime. If nothing happened go back and repeat until one of the boundary conditions is attained. Then go on to the next carrier and repeat procedure for all the launches of minority carriers. For each minority carrier launched keep track of origin location and boundary condition at fatality. The most important information gleaned is that the results depend only on the diffusion length, the geometry and the boundary conditions.

This paper compares Monte Carlo modeling results to spot scan measurements of High Density Vertically Integrated Photodiodes (HDVIP) manufactured in SWIR HgCdTe material. The primary photocurrent Iph is modeled by a Monte Carlo diffusion calculation in the p-type bulk. Carriers generated in the n-regions are always collected. The Monte Carlo calculation assumes a 3 x 3 mini-array of detectors surrounded by guard detectors. The result is a relative responsivity map that yields individual pixel "spot scan" response profile used to calculate expected MTF. Response of a SWIR HDVIP detector was acquired as a function of incident spot location. The spot was stepped 596 times in the X and also in the Y direction on 3.25 um increments to obtain a 2-D response profile of the detector. Lobes observed in the Monte Carlo modeling are confirmed by the measured 2-D spot scans. Fourier transforms of detector "spot scan" response profile provided experimental confirmation of MTF that corresponded to the modeled MTF.

7660-122, Session 4

The role of SWIR building blocks for hostile fire indication and missile warning systems

G. A. Tidhar, Optigo Systems, Ltd. (Israel)

Infrared Search and Track (IRST), Missile Warning Systems (MWS) and other optical target detection systems have established solutions in the MWIR, UV and LWIR bands. High quality, low cost SWIR imaging has been recently added as detection means technology and optical band. We analyze the differences in operation modes, physics and the effects of the optical signal observables, background and atmosphere for the different technologies, highlighting their respective pros and cons. Finally we bring further update on the development of new SWIR detection modules and their field results in HFI tests.

7660-24, Session 5

Small pixel a-Si/a-SiGe bolometer focal plane array technology at L-3 Communications

D. Morgan, J. Brady, S. K. Ajmera, T. Fagan, R. Gooch, C. M. Hanson, W. McCardel, T. Schimert, A. J. Syllaios, M. F. Taylor, L-3 Communications Infrared Products (United States)

Recent developments in low noise, high temperature coefficient of resistance (TCR) amorphous silicon (a-Si) and amorphous silicon germanium (a-SiGe) material has lead to the development of uncooled a-Si focal plane arrays with TCR in the range 3.2%/K to 3.9%/K which has been leveraged in the small pixel FPA development at L-3 CE Dallas. In the 17um pixel technology node at present, 1024x768, 640x480 and 320x240 FPAs have thus far been developed. All three formats employ wafer-level vacuum packaging with the 1024x768 representing the largest format uncooled FPA wafer-level packaged to date. FPA results from all three formats will be discussed and imaging data will be presented.

L-3 CE Dallas' small pixel format a-Si/a-SiGe-based FPA technology offers solutions for a wide range of new applications including wide field of view situational awareness/threat warning; persistent surveillance; and ground/airborne distributed aperture systems for 360o threat warning/ situational awareness which require high (up to megapixel) resolution. Microsensor applications including microUAV and unattended ground sensors which require low power, lightweight miniaturized sensors can also be addressed.

The technology development reported in this paper has been funded through the DARPA HOT MWIR Program (NBCH3060001, DARPA

7660-25, Session 5

A digital 25 µm pixel-pitch uncooled amorphous silicon TEC-less VGA IRFPA with massive parallel Sigma-Delta-ADC readout

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This paper presents an advanced 640 x 480 (VGA) IRFPA based on uncooled amorphous silicon microbolometers with a pixel-pitch of 25µm developed by Fraunhofer-IMS. The IRFPA is designed for thermal imaging applications in the LWIR (8 .. 14µm) range with a full-frame frequency of 30 Hz and a high sensitivity with NETD < 100 mK @ f/1. A novel readout architecture which utilizes massively parallel on-chip Sigma-Delta-ADCs located under the microbolometer array results in a high performance digital readout. Sigma-Delta-ADCs are inherently linear and a high resolution of 16 bit for a second-order Sigma-Delta-modulator followed by a third-order digital sinc-filter can be obtained. In addition to several thousand Sigma-Delta-ADCs the readout circuit consists of a configurable sequencer for controlling the readout clocking signals and a temperature sensor for measuring the temperature of the IRFPA. Since packaging is a significant part of IRFPA's price Fraunhofer-IMS uses a chip-scaled package consisting of an IR-transparent window with double-sided antireflection layer and a soldering frame for maintaining the vacuum resulting in reduced production costs. The IRFPAs are completely fabricated at Fraunhofer-IMS on 8" CMOS wafers with an additional surface micromachining process. In this paper the architecture of the readout electronics, the packaging, and the electro-optical performance characterization are presented.

7660-26, Session 5

High-performance uncooled amorphous silicon VGA IRFPA with 17-µm pixel pitch

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The high level of accumulated expertise by ULIS and CEA/LETI on uncooled microbolometers made from amorphous silicon enables ULIS to develop VGA IRFPA formats with 17µm pixel-pitch to build up the currently available product catalog.

This detector keeps all the innovations developed on the 25 µm pixel-pitch ROIC (detector configuration by serial link, low power consumption and wide electrical dynamic range. The specific appeal of this unit lies in the high spatial resolution it provides. The reduction of the pixel-pitch turns this TEC-less VGA array into a product well adapted for high resolution and compact systems.

In the last part of the paper, we will look more closely at the high electro-optical performances of this IRFPA and the rapid performance enhancement. We will insist on NETD trade-off with wide thermal dynamic range, as well as the high characteristics uniformity and pixel operability, achieved thanks to the mastering of the amorphous silicon technology coupled with the ROIC design. This technology node paves the way to high end products as well as low end compact smaller formats like 160 x 120 or smaller.

7660-27, Session 5

Low-resistance a-SiGe-based microbolometer pixel for future smart IR FPA

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In the outlook of the next 12µm pixel node uncooled IR FPA, the Laboratoire InfraRouge (LIR) of the Electronics and Information Technology Laboratory (LETI) is still pushing forward the amorphous silicon (a-Si) based microbolometer technology. A promising approach is the development of a lower resistance a-Si pixel, giving such a microbolometer IR sensor an edge for enhanced bias current capability, resulting in higher sensitivity.

With this goal in sight, the paper reports on a preliminary study that aims at incorporating a germanium ratio in the standard amorphous silicon film. This approach successfully resulted in a significant reduced thin film resistance. Both physical and electrical characteristics of these low resistance a-SiGe thin films are presented. From these basic parameter measurements, the paper further elaborates on the expected IR performance when such an a-SiGe film is applied to an uncooled FPA. Finally, we describe how this new generation of low resistance pixel fits perfectly with the maximum voltage requirement of advanced CMOS processes, which are needed for future smart ROIC and intelligent IR pixel.

7660-28, Session 5

DRS uncooled VO$_x$ infrared detector development and production status

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Significant progress has been made over the past decade on uncooled focal plane array (UFPA) technology development and production capacity at DRS and other domestic and oversea suppliers. This resulted in the proliferation of the uncooled IR detectors in the commercial and military markets. The uncooled detectors are widely used in fire-fighting, surveillance, industrial process monitoring, machine vision, and medical applications. In the military arena, uncooled detectors are being fielded in systems ranging as diverse as weapon sights, driver enhancement viewers, helmet mounted sights, airborne and ground surveillance sensors including UAVs and robot vehicles. Pixel dimensions have continually decreased with even an increase in pixel performance.

This paper presents an overview of the DRS 25 and 17 micron pixel pitch uncooled VO$_x$ detector technology development and production status. The DRS uncooled FPA products include 320x240 and 640x480 arrays while the larger 1024x768 17 micron pitch array is at engineering prototype quantities. Current production of the 25 micron pitch 320x240 and 640x480 arrays exceeds 5,000 units per month, supporting the U.S. military systems such as the Army thermal weapon sights (TWS) and driver vision enhancers (DVE). The next generation systems are moving towards the 17 micron pixel pitch detectors, several technical and production challenges were surmounted ranging from design, performance optimization, to manufacturing processes. Advancement in the small pixel technologies has enabled the 17 micron pitch detector performance to surpass their 25 micron pitch counterparts. To meet the future production demand of the 17 micron pitch UFPAs, DRS has made significant investment in production infrastructure to upgrade its tools. These investments include a new DUV stepper, coater, and plasma etcher plus improvements in its manufacturing techniques to enhance yield. These tools reduce the minimum line width in production below 0.35µm, and advanced tools have been qualified and are now producing the 17 micron 320x240 and 640x480 arrays.

As to technology development, DRS continues to engage in R&D activities focusing on VO$_x$ microbolometer detector design, packaging, test capability, materials and fabrication processes to further improve the detector performance, reliability, producibility and yield. Some of the results are summarized in this paper.

7660-29, Session 5

New developments in SCD's 17-µm VO$_x$ µ-bolometer product line

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Last year we have introduced the development program of SCD's 17µm pitch VGA VO$_x$ µ-Bolometer detector. Due to the overall size, weight and power advantages the 17µm pitch is currently being considered for the next generation systems such as thermal weapon sights (TWS), driver vision enhancers (DVE) and digitally fused goggles (DENVG).

In the first part of this paper we will discuss in detail the performance of this detector. Specifically, we will elaborate on the NETD, thermal time constant and operability. Detailed measurements for a wide temperature range will be shown as well.

In the second part, we will describe some new capabilities and features that are enabled by the advanced 0.18um VLSI technology. These features will be embedded in the new large format detector that is currently under development.

7660-30, Session 6

Advances in high-rate uncooled detector fabrication at Raytheon

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Over the past two years Raytheon has made a major investment aimed at establishing a high volume uncooled manufacturing capability. This effort has addressed three elements of the uncooled value stream, namely bolometer fabrication, packaging and calibration/test.

To facilitate a low cost / high volume source of bolometers Raytheon has formed a partnership with a high volume 200mm commercial silicon wafer fab. Over a 12 month period Raytheon has installed 200mm VOx deposition equipment, matched the metrology used on the Raytheon 150mm line, transferred the process flow used to fabricate Raytheon's double layer bolometer process and qualified the product. In this paper we will review the process transfer methodology and bolometer performance.

To reduce bolometer packaging cost and increase production rates, Raytheon has implemented an automated packaging line. This line utilizes automated adhesive dispense, component pick and place, wire bonding and solder seal. In this paper we will review the process flow, qualification process and line capacity.

Calibration and test has traditionally been performed using a number of temperature chambers, with increased throughput being obtained by adding more chambers. This comes at the expense of increased test labor required to feed the chambers and an increased energy and floor space foot print. To avoid these collateral costs, Raytheon has implemented an automated robotic calibration cell capable of performing in excess of 5,000 calibrations a month. In this paper we will provide an overview of the calibration cell along with takt time and throughput data.

7660-31, Session 6

Small pixel uncooled imaging FPAs and applications

R. J. Blackwell, BAE Systems (United States)

BAE Systems continues to make dramatic progress in uncooled microbolometer sensors and applications. This paper will review the latest advancements in microbolometer technology at BAE Systems including the status of the development of 17 micrometer pixel pitch detectors and imaging modules which will be finding their way into BAE Systems products and applications. Benefits include increased die per wafer and potential benefits to SWAP for many applications. Applications include thermal weapons sights, thermal imaging modules for remote weapon stations, vehicle situational awareness sensors and mast/pole mounted sensors.

7660-32, Session 6

A 320 x 240 pixel uncooled TEC-less infrared radiation focal plane array with the reset noise canceling algorithm

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We have developed a 22um pitch and 320 x 240 pixel low-cost uncooled infrared radiation focal plane array (FPA) which requires no thermo-electric cooler (TEC).

For IR detection, we use silicon single crystal series p-n junctions on SOI which can realize higher uniformity of sensitivity and lower voltage drift.

We also developed a low-noise readout circuit on the same SOI by 0.35um CMOS technology which can calibrate the substrate temperature variation in every frame period.

At the first of the frame period, the reference pixel line is selected and the input voltage of the each column amplifier is set to its threshold voltage at the same time.

Afterwards, the IR detection pixel line is selected row by row. Then the gate voltage of the column amplifier becomes higher by signal difference between the reference pixel and the IR detection pixel signal, which is independent of the chip temperature.

The issue has been that the 1/f noise from the reference pixel and the reset noise of the coupling capacitor which holds the reference voltage are also memorized as the reference noise, which causes the strong vertical line noise.

We have optimized the gate size of the analog transistors to reduce 1/f noise and also introduced the noise canceling digital algorithm to cancel the reset noise generated in the readout circuit.

Finally, the FPA realized noise equivalent temperature difference (NETD) of 0.1K.

We will discuss about ROIC noise analysis and reduction method and then make a survey of design tradeoffs to minimize NETD.

7660-33, Session 6

Design and performance of PIR security sensors using 10 to 25-µm microbolometer technology

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Previous reports to this SPIE forum have described a new generation of passive infrared (PIR) security sensors based on silicon microbolometer MOEMS technology. This technology is now patented and under development for commercial exploitation.

Hitherto, the objective has been to utilize the mosaic pixel focal plane array (MP-FPA) concept for PIR sensors using standard IC packaging sealed at atmospheric pressure. However the increasing availability of MEMS foundries and CMOS process-compatible FPA fabrication and wafer level vacuum packaging offers the potential for large scale production whilst at the same time achieving exceptional performance. This in turn extends the technology to other short range applications.

Access to higher resolution pattern definition has enabled design of 10 to 25µm silicon microbolometer mosaic pixel FPA giving further enhancement in NETD compared to previous reports. Furthermore, both FPA and ROIC can be fabricated on the same production line.

This paper gives the predicted performance of non-imaging PIR sensors for intruder detection and higher resolution imaging PIR sensors. The performances are given for atmospheric pressure and vacuum packaging, using a well established amorphous silicon material similar to that used in solar cells and thin film transistors. The predictions are based on an extensive database for this material. The technology can also be implemented in VOx or other silicon thin film materials.

7660-34, Session 6

Beyond the blackbody radiation limit: high-sensitivity thermal detectors

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The blackbody radiation limit has traditionally been set forth as the ultimate performance limit of thermal detectors, leading to a theoretical D^* of approximately $1.8 \times 10^{10} \, cmHz^{1/2}/W$ near room temperature. However, this fundamental radiation limit assumes that the detector absorbs uniformly throughout the thermal spectrum. In much the same way as photon detectors can achieve very high D^* because they do not absorb photon energies below their bandgap, so too can thermal detectors achieve high D^* except that thermal detectors are not limited to cryogenic operation. In both cases, the enhanced theoretical D^* is achieved because the radiation noise is reduced in a device that does not absorb at a uniform high level throughout the thermal emission band. There are multiple ways to achieve such high D^* in thermal detectors. One is to use materials that absorb only in a certain spectral range, just as in photon detectors. For example a detector made from PbSe, with proper optical coupling, absorbs only photons with wavelengths shorter than 4.9 m. The detectivity of such a device can theoretically exceed $7 \times 10^{10} \, cmHz^{1/2}/W$ in the MWIR. Even with Johnson and 1/f noise estimates included, it can still approach $4 \times 10^{10} \, cmHz^{1/2}/W$ in the MWIR. Another technique, applicable for narrowband thermal detectors, is probably even more powerful. Consider a thermal detector that is almost completely transparent. Here, the radiation noise has been reduced but the signal has been reduced even more. However, if the device is now placed inside an optical cavity, then at one wavelength and in one direction, the nearly transparent detector couples to the cavity resonance to absorb at 100%. Radiation from all other wavelengths and directions are rejected by the cavity or are absorbed only weakly by the detector. It is shown that theoretically, the D^* of these devices are roughly proportional to the inverse square root of the spectral resonant width under certain conditions. It is also shown that even including Johnson noise and 1/f noise, the practically achievable D^* approaches or exceeds $10^{11} \, cmHz^{1/2}/W$.

7660-151, Session 6

Amorphous silicon thin-films for uncooled infrared microbolometer sensors

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An increasingly important application of thin-film hydrogenated amorphous silicon (a-Si:H) is in infrared detection for microbolometer thermal imaging arrays. Key a-Si:H electrical transport properties that influence detector design and performance are resistivity and temperature coefficient of resistance (TCR). These properties have been measured over a wide temperature range for p- and n-type doped a-Si:H thin-films deposited by plasma enhanced chemical vapor deposited at substrate temperatures over 300C. Resistivity near and above room temperature follows an Arrhenius thermally activated dependence. The effects of doping on both the Arrhenius prefactor and activation energy will be discussed. As these transport properties are interrelated, optimization of thin-film preparation and processing is necessary to obtain high TCR with resistivity values compatible with the readout integrated circuit design. Such optimization of transport properties of a-Si:H films has been applied to the development of high performance ambient operating temperature (uncooled) microbolometer arrays.

7660-35, Session 7

Optical properties of antenna-coupled vanadium dioxide films

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Of the different materials exhibiting semiconductor to metallic phase transitions, some of the most researched from the point of view of their application in optical devices are those based on the group of vanadium oxides. Within this group, vanadium dioxide has become of considerable technological interest because of its exploitation as an infrared detector material. At temperatures below 68°C, the material exhibits semiconductor properties with an indirect absorption edge at about 2.5eV. On heating to temperatures in excess of 68°C, a shear crystallographic structural transformation occurs to enhance the degree of d-d orbital overlap, with a resulting delocalisation of electrons and formation of a metallic phase. The electrical transition of up to four orders of magnitude associated with this phase transition is reflected in its optical properties. The latter can be used to explore the benefits of antenna coupling where the vanadium dioxide forms a component element of the antenna array. Both inductive and capacitive designs have been considered and large area devices fabricated for test and comparison with theory. This paper will provide a summary of some of the results of the study, with emphasis on the LWIR spectral regime

7660-36, Session 7

High-performance longwave infrared bolometer fabricated by wafer bonding

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A novel micro-bolometer with peak responsivity in the far infrared region of the electromagnetic radiation is under development. It is a focal plane array (FPA) of pixels with a 25μm pitch, based on monocrystalline Si/SiGe quantum wells as IR sensitive material. The novelty of the proposed 3D process integration comes from the choice of several of the materials and key processes involved, which allow a high fill factor and provide improved transmission/absorption properties. Together with the high TCR and low 1/f noise provided by the thermistor material, they lead to bolometer performances beyond those of existing devices.

The thermistor material is transferred from the handle wafer to the ROIC wafer (read-out integrated circuit) by wafer bonding. The low thermal conductance legs that connect the thermistor to the ROIC are fabricated prior to the transfer bonding and are situated under the pixel. Depending on the type of the transfer bonding, the plugs connecting the legs to the thermistor are made before or after the bonding, resulting in two different configurations of the final structure. Using a low temperature oxide bonding and subsequent plugs formation result in through-pixel plugs. Pre-bonding plugs formation followed by thermo-compression bonding result in under-pixel plugs. The pixels are subsequently released by anhydrous vapor HF of the sacrificial oxide layer.

The ROIC wafer containing the released FPAs is subsequently bonded in vacuum with a silicon cap wafer, providing hermetic encapsulation at low cost. Antireflection coatings and a getter material are deposited on the cap wafer prior to bonding, ensuring high performance of the bolometer.

7660-37, Session 7

Photomechanical imager FPA design for manufacturability

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In a conventional thermal imager, the layout of the monolithically integrated infrared sensor FPA must strictly adhere to the layout of the readout integrated circuit (ROIC). Thus, while any modification at the pixel level may require only changing the FPA layout, modifications at the FPA level may require changing both the FPA and ROIC layout. In a photomechanical imager, the readout of the infrared sensor FPA is performed optically, instead of electrically, with a physically separated commercial CMOS imager serving as the ROIC. The modularity of the photomechanical imager allows modifications at the FPA level to be made without requiring any change in the CMOS imager. This creates a critical advantage for the optical readout architecture: because there is no physical interdependency between the infrared sensor FPA and CMOS imager, multiple pixel designs can be fabricated in the same FPA layout and simultaneously use a single CMOS imager for readout. Virtually unlimited flexibility in pixel design is possible. In this paper, we will present results from the simultaneous fabrication and testing of 12 FPA designs located in the same sensor chip. Variations are made to both the sensor pixel pitch and pixel design without impact to the readout, enabling the rapid prototyping and evaluation of every design in the layout. As a result, the optical readout architecture opens up unprecedented potential for design for manufacturability of the infrared sensor FPA by efficiently down selecting and optimizing the pixel design and providing the capability for rapid customization.

7660-38, Session 7

Skin depth effects in wavelength-selective infrared microbolometers based on lossy frequency selective surfaces

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Past work has discussed infrared absorption using a patterned thin resistive sheet as the frequency-selective absorber for use in wavelength-selective long wave infrared (LWIR) microbolometer focal planes arrays. These patterned resistive sheets are essentially slot antennas formed in a lossy resistive ground plane layer placed a quarter-wavelength in front of a mirror. Design studies have shown that for efficient IR absorption cross-shaped slots require a lossy sheet with the sheet resistance close to 1Ω/ . For realistic metal layers, however, the skin effect produces a complex surface impedance that can be quite lager in the LWIR band. In this paper we present calculations showing that metal layers of thickness between one and three skin depths can provide excellent absorption in the LWIR. These full wave calculations show that using real materials such as aluminum or copper can produce narrowband spectral absorption in the LWIR.

7660-39, Session 7

Status of Sirica novel low-cost IR detector development program

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Sirica novel LWIR photonic detector is based on continuous LWIR/ VNIR up-conversion layer optically coupled to high resolution CMOS sensor, operating at room temperature and assembled in a non-vacuum package. This concept for low cost IR opens new opportunities for civil mass-market thermal cameras, especially for the outdoor long range applications. Using small pixel standard CMOS sensor opens up new methods to reduce noise and improve the image quality of the IR detector. In this paper we describe Sirica development program status, the detector architecture and the unique features of this detector. Recent results of the prototype will be presented.

7660-40, Session 7

Characterization of second-generation advanced dynamic pyro-electric focal plane array

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The pyroelectric effect has been previously characterized for single-pixel elements consisting of strontium bismuth tantalate (SBT) ferroelectric material as the sensing element. These pixels have been integrated into second-generation focal plane arrays. The constituent second-generation array pixels include a thermal insulating layer and an infrared (IR) absorber layer. These MEMS-less device arrays are operated in active mode, a technique that eliminates the need for a radiation chopper found in passive pyroelectric IR imagers. This paper analyses and characterizes the results of precursor 2x2 to 32 x 32 second-generation arrays of SBT sensing elements, the active detection mechanism, and the unique read-out, interrogation signal generation, and synchronization electronics. The second-generation 32x32 pixels array implemented to demonstrate the performance of a 1k-pixel array as precursor to larger size arrays using different pixel dimensions is described. The active mode detection, in addition to eliminating the use of a chopper, enables the dynamic partition of the array into pixel domains in which the pixel sensitivities in each domain can be adjusted independently. This unique feature in IR detection, not readily found in other types of IR imagers, can be applied to the simultaneous tracking of diverse contrast objects. By controlling the absorber material thickness, the arrays can additionally be optimized for maximum response at specified wavelengths by means of quarter-wavelength interferometry.

7660-42, Session 8

Developing high-performance superlattice IRFPAs for defense: challenges and solutions

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The task of demonstrating a next-generation ballistic missile defense system (BMDS) places various challenging requirements on infrared focal plane array (IRFPA) performance. However, with limited budgets and reduced technology development cycles, devising and implementing a winning strategy is essential, especially when requirements are relatively diverse. Certain applications require large-format FPAs for a wide field of view. These FPAs must be able to detect IR signatures at long-wavelengths (LWs) with background limited performance (BLIP) and with minimal spatial cross talk. Other applications require medium format dual-band capability with BLIP performance as well as minimal spectral cross talk. Space based applications require that detector arrays and readout integrated circuits (ROICs) are radiation hardened. These application-driven sensor system requirements flow down and translate to necessary improvements in detector material uniformity and defect density, large-size substrate availability, detector array processing and passivation capability, as well as detector and ROIC structure trades. There is room to explore technologies and make new systems outperform

existing systems. In addition, long-term research and development cost, product availability, and industry sustainability are also to be considered. This presentation will elaborate details of the new comprehensive integrated program designed to demonstrate a set of IRFPAs that offer a promising solution to the BMDS. Discussions will cover team arrangement, performance metrics, technical issues, and solutions. The presentation will also highlight the latest results in superlattice detector performance at single-element level and at array level, and preliminary analysis on the performance gaps between them. Comparisons will also be made between current detector performance and theoretical predictions. A plan for continuous performance improvement will be reasoned and presented.

7660-43, Session 8

Type-II antimonide-based superlattices for the third-generation infrared focal plane arrays

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Infrared detection technologies are now entering the third generations with more and more demanding requirements for higher device performance, higher resolution, multiple color detectors as well as better yield and lower manufacturing/operating cost. With unique advantages and significant progress achieved in recent years, Type II antimonide based superlattices (T2SL) are making firm steps toward the new era of focal plane arrays. Benefiting from the III-V zinc blende structure, the material system can be grown with high quality on large size, non-native GaAs substrates for low cost and expandable fabrication process. Excellent uniformity material can be achieved thanks to the precise control of layer thicknesses, enabling uniform detection at the L/VLWIR and facilitating the fabrication of large format arrays. Moreover, thousands of superlattice configurations of this low dimensional system allow for the selection of dual detection band designs with perfectly lattice matched condition between the two channels and the native substrate; which assures the realization of high quality, high performance two color detectors. Finally, the flexible atomic engineering capability is a unique feature of T2SL, which gives birth to novel device architectures such as M-structure, pMp-design for high performance VLWIR detection and efficient two color detector design.

In this talk, we will present the four themes for the third generation imagers at the Center for Quantum Devices: high performance focal plane arrays on non-native GaAs substrates, high resolution 1Kx1K LWIR focal plane arrays, LWIR/LWIR two color focal plane arrays and VLWIR focal plane arrays using the pMp minority electron unipolar photodetectors.

7660-44, Session 8

Type-II superlattices: the Fraunhofer perspective

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Over the last years, the InAs/GaSb superlattice (SL) technology has shown rapid and steady progress. The staggered, type-II band alignment gives rise to a widely adjustable bandgap covering the infrared (IR) spectral range from 3-30 μm. A long diffusion length of minority electrons enables the realization of photodiodes with very high quantum efficiency. Compared to CdHgTe, theory promises significantly lower dark current in InAs/GaSb SL photodiodes due to reduced tunnelling contributions and lower Auger recombination rates.

The Fraunhofer Institute for Applied Solid State Physics (IAF) looks back on a long tradition of fundamental materials research on this exiting system as well as the successful development of small volume fabrication processes for mono- and bispectral IR focal plane arrays. Stand-alone, high-performance SL imagers are realized in a close

cooperation between Fraunhofer IAF and AIM Infrarot-Module GmbH. The talk will address the current state as well as future perspectives of the InAs/GaSb type-II SL technology.

7660-45, Session 8

Type-II superlattice materials research at the Air Force Research Laboratory

G. J. Brown, Air Force Research Lab. (United States)

Type-II superlattice (SL) materials research in the Air Force Research Laboratory began in 1988. This materials system holds held great promise as the III-V equivalent to HgCdTe alloys for infrared detection. Great progress has been made on the epitaxial growth of InAs/Ga1-xIn xSb superlattices in the past twenty years by a number of research groups. However, not all of the materials issues have been solved. To continue to resolve these limiting materials issues, basic superlattice materials, without photodiode fabrication, are used to characterize the impact of growth processes and SL design on the structural, electrical and optical properties. An integrated approach of theoretical modeling, in-house molecular beam epitaxy, and a host of materials measurement techniques is employed to study the optimization of the superlattices for infrared detection. In the past few years the majority of the samples grown in-house have been designed for the mid-infrared wavelength band. Therefore mid-IR SL compositions will be the main focus in this presentation. Recent progress on understanding the complex interplay between InAs/GaSb superlattice composition and fundamental electrical and optical properties will be covered.

7660-46, Session 8

Status of multi-wafer production MBE growth of Type-II SL at IntelliEPI

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During the past year, IntelliEPI has set up an Sb-capable multi-wafer production MBE reactor to support the development of Type-II Superlattice (T2SL) based on InAs / In(AlGa)Sb material system particularly for IR FPA applications. Our production MBE reactor is capable of supporting multi-2", 3", 4", and a single 6" GaSb substrate as it becomes available. The T2SL epi growth capability was recently developed under the MDA-FastFPA program. Progress on T2SL epi materials growth at IntelliEPI will be discussed. This includes a) status of the T2SL technology transfer to IntelliEPI from the national labs (NRL, & NASA-JPL), b) epi materials growth characteristics and uniformity across multi-wafer configuration, and c) in-situ sensor capability at IntelliEPI to monitor and control SLS epi growth process.

7660-47, Session 8

MBE growth of Sb-based type-II strained layer superlattice structures on multiwafer production reactors

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Ga(In)Sb/InAs-based strained-layer superlattices (SLS) have received considerable attention recently for their potential in infrared (IR) applications. These heterostructures create a type-II band alignment such that the conduction band of InAs layer is lower than the valence band of Ga(In)Sb layer. By varying the thickness and composition of the constituent materials, the bandgap of these SLS structures can be tailored to cover a wide range of the mid-wavelength and long-wavelength IR absorption bands. Suppression of Auger recombination

and reduction of tunneling current can also be realized through careful design of the Type-II band structure.

The growth of high-quality Ga(In)Sb/InAs-based SLS epiwafers is challenging due to the complexity of growing a large number of alternating thin layers with mixed group V elements. In this presentation, the development of a manufacturable growth process by molecular beam epitaxy (MBE) using multi wafer production reactors will be discussed. Various techniques were used to analyze the quality of the MBE material. Structural properties were evaluated by high resolution x-ray diffraction and cross-sectional transmission electron microscopy. Optical properties were assessed by low-temperature photoluminescence measurements. Surface morphology and roughness data as measured by Nomarski optical microscope and atomic force microscope will be presented. IV characteristics and responsivity measurements based on a quick loop feedback process for variable size mesa diodes fabrication will be discussed.

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7660-48, Session 8

Epitaxy ready 4" GaSb substrates: requirements for MBE grown type-II superlattice infrared detectors

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In this paper we describe the crystal growth and surface characterisation of 4" GaSb substrates suitable for the epitaxial deposition of type II superlattice infrared detectors. Results will be presented on the production of single crystal 4" GaSb ingots grown by the liquid encapsulated Czochralski (LEC) technique , supported by the analysis of bulk material quality by X-ray topography (XRT). This work will demonstrate that 4" wafers can be produced that are of comparable crystal quality to current 2" and 3" GaSb material. This study will also describe how various techniques were used to characterise the quality of the bare substrate and epitaxial material grown on top of 4" GaSb substrates. Surface oxide properties of the GaSb substrates will be characterised by spectroscopic ellipsometry (SE). Growth desorption process were monitored using energy electron diffraction (RHEED). Surface morphology and roughness before and after epi growth were evaluated via Nomarski optical microscope and atomic force microscope (AFM). Data on the structural properties of the Sb-SLS epi material from high-resolution x ray diffraction (XRD) and cross-sectional transmission electron microscopy (XTEM) will be presented.

7660-49, Session 8

Optimization of MWIR type-II superlattices for infrared detection

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Type II superlattices (SLs) offer a broad range of design degrees of freedom to help optimize their properties for infrared detection. Under the AFRL STEPS contract, we focus on mid-wavelength infrared (MWIR; 2-5 μm cutoff wavelength) Type II structures with two-layer InAs/GaInSb and four-layer "W-structure" InAs/GaInSb/InAs/AlInGaAsSb SL periods. One design degree of freedom permits a reduction in the density of final states available to Auger processes, thereby suppressing this nonradiative recombination mechanism that tends to limit the performance of infrared photon detectors at high operating temperatures. Designing an SL to exhibit Auger suppression via this final state optimization becomes more challenging as the SL band gap increases due to the increasing number of SL subbands that exist in critical regions of the electronic band

structure. MWIR SLs are therefore particularly challenging to optimize. Our previous work considered a MWIR SL for laser applications and found that final state optimization to suppress Auger recombination can produce pronounced recombination lifetime improvements at 77 K but has little effect at 300 K. This work will report on final state optimizations for 5 μm cutoff SLs in the 200-225 K operating temperature range.

7660-50, Session 9

High-performance LWIR type-II strained layer superlattice focal plane arrays

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Type-II strained layer superlattices (SLS) are a rapidly maturing technology for infrared imaging applications, with performance approaching that of HgCdTe. Teledyne Imaging Sensors (TIS), in partnership with the Naval Research Laboratory (NRL), has recently demonstrated state-of-the-art, LWIR, SLS 256 x 256 focal plane arrays (FPAs) with cutoff wavelengths ranging from 9.4 to 11.5 μm. The dark current performance of these arrays is within a factor of 10-20 of (state of the art) HgCdTe. Dark current characteristics of unpassivated and passivated devices exhibit non surface limited behavior, essential for FPA applications. TIS has also demonstrated rapid substrate thinning processes for increased infrared transmission through the GaSb substrate. In addition to this work, this presentation will discuss the recent developments of 1K x 1K LWIR SLS FPAs.

7660-51, Session 9

Characterization of barrier effects in superlattice LWIR detectors

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To support the development of LWIR sensors, we report progress with diodes in type-II strained layer superlattice structures built in the InAs/GaSb/AlSb materials system. A key feature of the devices is a pair of complimentary barriers, namely, an electron barrier and a hole barrier formed at different depths in the growth sequence. This work is a collaborative effort between Raytheon Vision Systems and Jet Propulsion Laboratory, with design and growth being performed at JPL, and processing and testing at RVS. Mesas were formed by wet etching followed by surface passivation with plasma-deposited silicon dioxide. Test devices were hybridized with indium bump bonding to fanout boards providing direct contact to individual diodes. We have analyzed the current-voltage characteristics as functions of temperature and junction area, and have measured the spectral response and quantum efficiency as functions of bias voltage. From the temperature dependence of the dark current in a typical case, we infer that the effective barrier height is 0.20 eV. This indicates that dark current is limited by the barriers rather than diffusion or GR mechanisms occurring within the absorber region where the bandgap is 0.13 eV. The barriers prove to be very effective in suppressing the dark current. In the case of a detector having a cutoff wavelength of 9.24 μm, we find R0A > 1E5 ohm cm2 at 78 K, as compared with about 100 ohm cm2 for an InAs/GaSb homojunction of the same cutoff. For good photo response, the device must be biased to typically -200 or -250 mV. In this condition we find the internal quantum efficiency to be greater than 50%, while the RA remains above 1E4 ohm cm2. Thus, the device shows both high RA and good quantum efficiency at the same operating bias.

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was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. We acknowledge guidance from Ranty Liang of Jet Propulsion Laboratory.

7660-52, Session 9

Fabrication and performance of InAs/GaSb-based superlattice LWIR detectors

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We describe our recent efforts in developing InAs/GaSb-based superlattices for LWIR detectors on the MDA-funded FastFPA program. The structural properties of the device structures grown by MBE at HRL were evaluated using optical microscopy, x-ray diffraction, atomic force microscopy and fabricated as photodiodes. InAs/GaSb superlattice wafers received from trusted entities, as part of the FastFPA program, were also fabricated, and the properties of the LWIR detectors were evaluated. Both n-on-p as well as p-on-n devices were fabricated and tested. Halogen-based dry etch process was developed to provide mesa structures with a high aspect ratio, such as that needed for developing dual-band detectors. Following dry-etching, a wet etch process was utilized to obtain dark currents comparable to our baseline wet etching process. SiO2 and semiconductor regrowth processes were evaluated for the passivation of mesa structures. I-V and spectral response characteristics, and dependence on the LWIR photodiode dark current on the fabrication processes will be discussed.

7660-53, Session 9

SLS technology: the FPA perspective

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To be commercially viable, longwave infrared focal plane arrays (FPAs) based on Type-II InAs/GaSb strained layer superlattices (SLS) have to meet the price and performance of InSb and QWIP FPAs. Are we there yet? This talk will present current results from QmagiQ. While imaging has been demonstrated in prototype FPAs, issues such as epi material quality, surface passivation, pixel operability, array cost and yield remain. Our talk will outline our approach to tackling these problems and the results of our efforts.

7660-54, Session 9

Recent developments in type-II superlattice-based infrared detectors

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Much has been accomplished in the last few years in advancing the performance of type-II superlattice (T2SL) based infrared photodiodes largely by focusing on device and heterostructure design. Quantum efficiency (QE) has increased to 50% and higher by using thicker absorbing layers and making use of internal reflections, and dark current has been reduced by over a factor of ten by using bandstructure engineering to suppress tunneling and generation-recombination (G-R) currents associated with the junction. With performance levels of LWIR T2SL photodiodes within an order of magnitude of that of HgCdTe (MCT) based technology, however, there is now renewed interest in understanding fundamental materials issues, to both move performance

toward theoretical Auger limits, and to facilitate the task of transitioning T2SL growth from laboratories to commercial institutions. Here we discuss recent efforts at NRL to further this understanding by using structural and electronic probes. Results from electron beam induced current (EBIC) imaging and analysis of point defects in T2SL photodiodes will be presented, showing differentiated behavior of bulk defect structures. We will also describe a study comparing the intended vs. as-grown structures of T2SL photodiodes using cross-sectional scanning microscopy (XSTM). Using parameters extracted from XSTM images, we obtain detailed knowledge of the composition and layer structure of as-grown T2SL structures. We then examine correlations between specific structural features, such as group V cross-incorporation and interface structure, with photoluminescence energy and intensity.

7660-55, Session 9

Antimonide-based barrier infrared detectors

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The nearly lattice-matched InAs/GaSb/AlSb (antimonide) material system offers tremendous flexibility in realizing high-performance infrared detectors. Antimonide-based alloy and superlattice infrared absorbers can be tailor-made to have cutoff wavelengths ranging from the short wave infrared (SWIR) to the very long wave infrared (VLWIR). They can be used in constructing sophisticated heterostructures to enable advanced infrared photodetector designs. In particular, they facilitate the construction of unipolar barriers, which can block one carrier type but allow the un-impeded flow of the other. Unipolar barriers are used to implement the barrier infra-red detector (BIRD) design for increasing the collection efficiency of photo-generated carriers, and reducing dark current generation without impeding photocurrent flow. We report our recent efforts in achieving state-of-the-art performance in antimonide alloy and superlattice based infrared photodetectors using the BIRD architecture. Specifically, we report a 10 micron cutoff superlattice device based on a complementary barrier infrared detector (CBIRD) design. The detector, without anti-reflection coating or passivation, exhibits a responsivity of 1.5 A/W and a dark current density of 1×10^{-5} A/cm2 at 77K under 0.2 V bias. It reaches 300 K background limited infrared photodetection (BLIP) operation at 87 K, with a black-body BLIP D* value of 1.1×10^{11} cm-Hz1/2/W for f/2 optics under 0.2 V bias. CBIRD follow-on device and focal plane array (FPA) development results will also be presented at the conference. In addition, we will report results in short- and mid-wave high operating temperature barrier infrared detector development.

7660-56, Session 9

Growth and performance of superlattice-based long wavelength Complementary Barrier Infrared Detectors (CBIRDs)

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The closely lattice-matched material system of InAs, GaSb, and AlSb, commonly referred to as the 6.1Å material system, enables many unique approaches for producing high performance infrared detectors. The flexibility of the materials system allows for the use of artificial bandgap "superlattice" structures, as well as the elegant design of barrier infrared detectors (BIRDs). BIRD arrays with superlattice absorbing regions offer great potential both for higher-operating temperature and low background applications. The realm of possible applications is further enhanced by the availability of GaSb substrates in diameters of up to 100mm. Our team has focused on the manufacturability of BIRD and superlattice-based focal plane arrays (FPAs) by leveraging off of an existing knowledge base for producing FPAs with III-V materials as

well as the dedicated antimonide growth program at JPL. In this paper, we will discuss molecular beam epitaxy (MBE) growth techniques for producing large area device wafers in the antimonide material system, the performance of our latest complimentary barrier infrared detector (CBIRD) device designs, and imaging results in both the mid and long wavelength infrared.

7660-57, Session 9

Heterostructure band engineering of longwave infrared photodiodes with type-II InAs/GaSb superlattices using unipolar current blocking layers

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Long wave infrared (LWIR) detectors based on type-II InAs/GaSb superlattices have gained a lot of attention in the past few years. One of the big advantages of the SLS system is the flexibility to engineer the bandstructure of the device. Several architectures such as the nBn1, CBIRD2 and M-structure3 have been demonstrated. In this work, we report on a systematic theoretical and experimental study of an InAs/GaSb SLS PIN diode containing an electron blocking layer near P contact and a hole blocking layer near N contact. This is expected to lead to decrease in the diffusion, Schockley-Read-Hall and tunneling currents. Simulations reveal that the dark is decreased by three orders of magnitude, as compared to conventional PIN diode. The device consists of an N type contact layer, made of 8ML/8ML InAs/GaSb superlattice, also acting as a hole blocking layer, followed by the longwave superlattice absorber region, followed by an AlAs0.08Sb0.92 layer, a wider bandgap material lattice matched to the substrate to act as the electron blocking layer (unlike the superlattice based electron blocking layer in CBIRD2 design). In the reverse bias, AlAs0.08Sb0.92 layer blocks the minority electrons from reaching the P contact while offers no barrier for hole. Similarly, midwave superlattice N contact layer blocks holes and present no barrier for electrons. The minority carriers generated in P contact layer are blocked from reaching the absorber region by the electron blocking layer, thus reducing the dark current. Our simulations show that the electric field drops away from the absorber region in the barrier layers of wider band-gaps, which further reduces dark current. These results will be discussed in detail in the presentation.

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7660-58, Session 9

SU-8 passivation of type-II InAs/GaSb strained layer superlattice detectors

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Type-II short period InAs/GaSb strained layer superlattices (SLSs) are

a promising technology for the mid-wave (MWIR,3-5 microns) and long-wave (LWIR, 8-12 microns) infrared (IR) regions. Presently, mercury-cadmium-telluride (MCT) and quantum-well infrared (QWIP) detectors are prominent technologies. However, MCT detectors are characterized by low electron effective mass (~0.009m0) resulting in excessive dark current due to tunneling, especially at longer wavelengths. QWIPs are limited to cryogenic operation temperatures (below 60 K) due to relatively high values of thermally generated dark current caused by electron tunneling between wells. Moreover, the quantum efficiency in QWIPs is limited to 20-30%. In InAs/GaSb SLS, tunneling currents are reduced due to the higher electron effective mass and Auger recombination is expected to be suppressed due to the large splitting between heavy-hole and light-hole valence subbands as well.

In order to achieve high signal-to-noise ratio for focal plane arrays (FPAs) based on InAs/GaSb SLS, FPA pixel size has to be scaled to 20-30 microns. In this case, the surface leakage current originating from etched mesa sidewalls is the dominating component of dark current. To surmount this problem, several passivation methods have been proposed. However, these passivation techniques either complicate the fabrication process of FPA or are susceptible to the device cut-off wavelength. In this paper, we report on SU-8 passivation for MWIR and LWIR InAs/GaSb SLS detectors. We observed four orders of magnitude reduction in the dark current and a five fold increase in surface resistivity for MWIR SLS detector. The zero bias responsivity and detectivity had 0.9 A/W and 3.5 x 10^12 Jones, respectively, for MWIR passivated diodes (77K). Improvement of performance characteristics of LWIR SLS detectors will be discussed in the presentation.

7660-59, Session 9

Carrier lifetime measurements in InAs/GaSb strained layer superlattice structures and binary bulk layers

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Minority carrier lifetime and interband absorption in midinfrared range of spectra were measured in InAs/GaSb strained-layer superlattices grown by MBE on GaSb substrates. The carrier lifetime was determined by time-resolved photoluminescence (PL) and from analysis of PL response to sinwave-modulated excitation. Study of PL kinetics in frequency domain allowed for direct lifetime measurements with the excess carrier concentration level of 3.5´1015 cm-3. Typical minority carrier lifetimes of 80 ns at T = 77 K were obtained from dependence of the carrier lifetime on excitation power. SLS structures with similar absorption wavelengths but with different InAs and GaSb layer thicknesses were investigated. Base-line numbers for the life-times in bulk layers of GaSb and InAs will also be presented.

7660-154, Session 9

Dual-carrier multiplication high-gain MWIR strain layer superlattice impact ionization engineered avalanche photodiodes for linear mode photon counting applications

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A novel heterostructured dual carrier multiplication extremely high gain MWIR InAs/InGaSb Type II Strain Layer Superlattice (T2SLS) impact ionization engineered (I2E) APDs for single photon counting applications. Spatially separated T2SLS electron and hole multiplication regions are designed using 14 bank k.p bandstructure modeling.

Bandstructure engineered energy resonance in the conduction (for electron multiplication region) and valence bands (for hole multiplication region) results in extremely low and high values of k , ratio of electron to hole impact ionization coefficients, respectively.

This helps us achieve extremely low excess noise multiplication regions. In the novel dual carrier device, the I2E T2SLS electron and hole multiplication regions are placed right next to each other. This allows for a carrier feedback between the electron and hole multiplication regions. The holes generated, by impact ionization, in the electron multiplication region move to the hole multiplication region and create secondary electrons and holes. The secondary electrons move to the electron multiplication region and continue the impact ionization process. This feedback between the electron and hole multiplication regions allows for extremely high gain values for the overall device.

However, the individual gain of the electron (Me) and hole multiplication (Mh) regions can be kept extremely low (for Me = 17 and Mh = 1.3 - both multiplication regions are below breakdown , the overall gain M = 25000 , this can be achieved at a reverse bias of 5.4V in a T2SLS dual carrier multiplication MWIR APD (c = 4.75µm)). The effective k is designed to be approximately .03. Such low bias (Vreverse = 5.4V) operation of the MWIR APD (M = 25000) allows for single photon counting (active operation) and passive mode operation on the same pixel using standard ROIC and this opens up possibility of large format dual mode imaging arrays. More details regarding device design, MBE growth, device fabrication and characterization will be presented at the conference.

7660-60, Session 10

MWIR continuous zoom with large zoom range

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Multiple fields of view are achieved by two methods. The system can have optical groups that flip in and out to change the field of view, and/or optical groups that move axially to change the field of view. For flip in systems, the fields of view are discreet and they may have greatly different fields of view. A zoom system can have a continuous change in the field of view, but is often limited in the field of view range that can be achieved. Corning Incorporated has developed a thermal imaging zoom system with greater than 30X zoom range. With a solid fundamental design and appropriate selection of moving group focal lengths, the zoom system provides continuous changes in the field of view from the narrow field of view to the wide field of view. Corning accomplished this result in a short package with just two moving groups. The system is for the MWIR band.

7660-61, Session 10

An alternative approach to infrared optics

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The MONTAGE program sponsored by the Microsystems Technology Office of the Defense Advanced Research Projects Agency (DARPA) resulted in the demonstration of a novel approach to designing compact imaging systems. This approach was enabled by an unusual four-fold annular lens that was originally designed and demonstrated for operation exclusively in the visible spectral band. To help reach DARPA's goal of an ultra-thin imaging system, the folded optic was fabricated by diamond-turning concentric aspheric rings on both sides of a CaF2 core. The optical properties of the core material ultimately limit the operating bandwidth of such a design. In this paper, we present the latest results of an effort to re-engineer and demonstrate the MONTAGE folded optics for imaging across a broad spectral band. The broadband capability is achieved by taking advantage of a new design that substitutes a hollow

core configuration for the solid core. In addition to enabling additional applications for the folded optics, the hollow-core design offers the potential of substantially reducing the weight and cost in comparison to an alternative solid-core design. We present new results characterizing the performance of a lens based on the new design and applied to imaging across the long-wave infrared spectral band. We also describe previous work demonstrating how the folded annular design of the optics can be exploited to achieve dual-band capability in a compact coaxial architecture.

7660-62, Session 10

Design of an optics-integrated cryogenic IR detector

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Cryogenically cooled IR detectors, which are used in applications such as situational awareness, search & track, missile launch and approach warning, typically use wide angle, single field of view optical systems. We describe a complete IR imaging optical assembly for such applications, which is mounted inside a cold shield and is maintained at the stabilized cryogenic temperature inside the dewar. A typical system houses two to four lenses and a cold filter, and weighs 5 grams or less. Despite this integration and added complexity, the resulting Detector-Dewar-Cooler Assembly (DDCA) has overall dimensions similar to those of equivalent-performing DDCAs without integrated optics. Compact designs integrating wide-angle optics and a warm, high-magnification, telescope module for narrow FOV applications are seen as a straightforward extension of our system. We conclude with an in-depth, technical overview describing the design considerations for a typical wide-field imaging system.

7660-63, Session 10

Molding aspheric lenses for low-cost production versus diamond turned lenses

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Small lenses with aspheric surfaces can be either molded or single point diamond turned. The latter is commonly used for very small quantities or military applications where costs are not the main driving factor. This method does not suit the consumer market with high performing optics sold at a low price. The prices for new products are constantly declining. Infrared cameras for example are presently still too expensive for the consumer market, but the trend to lower costs is visible as well. The GPS technology can be seen as a representative example that started with a few very costly products and has now become a low-cost consumer product. High performance of optical elements or systems, paired with low manufacturing costs, require adapted manufacturing processes.

This paper presents the glass molding process as a means to produce glass lenses at low cost and compares it with a Single Point Diamond Turning process.

The molding process is unique in that lenses are molded to their final size without a secondary operation. Discussed are the capabilities and costs of our molding process in comparison with single point diamond turning. Addressed are further details relating to tolerance (high precision and standard precision), possible lens shapes, aspect ratios, present sizes with maximum 22mm outer diameter and future sizes with maximum 50 mm outer diameter as well as capacities and product examples. Actual manufacturing data will be provided for molding and diamond turning of identical lenses.

7660-64, Session 10

1280 x 960 pixel microscanned infrared imaging module

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Observation operations usually rely on long distance wide field-of-view devices. In today's fast evolving technology, there is an increasing demand for high resolution infrared modules that can be rapidly turned into a complete autonomous device whether it is for military or industrial purposes. Based on this concept, INO has developed a 1280 x 960 pixel infrared imaging module that provides high resolution as well as wide field-of-view coverage.

The infrared module features a1280 x 960 pixel image with 12.5 um efficient pixel pitch. The module integrates a microscanned catadioptric optics with 50 mm focal length, capable of doubling the effective resolution of a 640 x 480 pixel uncooled FPA and an IRXCam module to generate a high resolution image. The microscan system doubles the dimension of the image along each axis compared to the original FPA dimensions while reducing the effective pixel pitch and at the same time reducing or eliminating the aliasing effects. The aluminum based optics is compact and lightweight. The camera output is 16-bit raw signal output at 60 Hz, and the module gives total access to the detector configuration parameters to ease the developer's integration process. TECless operation minimizes module size and power consumption. The high resolution camera module can be configured for outdoor operation from -30C to +60C with 200C scene dynamic range at maximum sensitivity. Windowing capability provides flexibility on frame frequency, sensitivity and choice of operating field of view. In this paper, the catadioptrics optics with integrated microscan and the camera core will be reviewed as well as its performances. The control software functionalities will be detailed. Some typical imaging examples in outdoor conditions will be presented.

7660-65, Session 10

Integration of advanced optical functions on the focal plane array for very compact MCT-based micro cameras

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Over the past decade, several technological breakthroughs have been achieved in the field of optical detection, in terms of spatial and thermal resolutions. The actual trend leads to the integration of new functions at the vicinity of the detector.

This paper presents two types of integrated optics in the cryo-cooler, close to the MCT infrared detector array.

The first one, for spectro-imaging applications, is a Fourier-transform microspectrometer on chip (MICROSPOC), developed for very fast acquisition of spectral signatures. Experimental results will be discussed comparing two different technological approaches based on integrated or hybridized structures.

The second one, for large field of view applications, illustrates the high potentiality of the integration of advanced optical functions in the Dewar of MCT detectors.

7660-66, Session 10

A Zero-Focal-Length superlens for QWIPs and other infrared detectors

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We introduce a Zero Focal Length Superlens, which is able to concentrate light on a very short scale. The device is based on the corrugation of the interface between a perfect reflector and a propagating medium. Surface waves are confined at the surface of a perfect electrical conductor, squeezed at the centre of the lens, and coupled to incident radiation. The structure is based on the combination of two Bragg mirrors for surface plasmons and a coupling grating. Sub-wavelength confinement of electromagnetic waves is demonstrated experimentally in the gigahertz range, and can equally be extended to any part of the electromagnetic spectrum. The ZFL superlens design uses a single etching depth, convenient for technological processing, even at sub micron scales. The concept can be implemented for QWIPs but also for MCT or InSb detectors

7660-67, Session 10

Dynamic Sunlight Filter (DSF): a passive way to increase the dynamic range in Visible and SWIR cameras

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The need to regulate and control light power is relevant for every type of camera, from simple point and shoot and up to a very sophisticated security cameras. Regulating optical power levels in cameras or other optical systems, requires today an electronic feedback control or offline data processing, which results in complex and expensive systems. Moreover, optical systems, sensors and cameras, are susceptible to saturation or damage caused by high power of light impinging them. This light source can be a high power laser, or other light sources, such as the sun. This problem calls for a device that will switch off the propagating power when the maximal allowed power is exceeded.

We explore the unique capabilities and advantages of nanotechnology in developing next generation non-linear components and devices to control and regulate optical power in a passive way. We present a non-linear, solid-state passive dynamic sunlight filter covering the visible and the near IR wavelengths range. When light increases continuously, such as in the case of sunrise, the DSF transmission decreases according to the amount of the incident light, resulting in a darkened state. The darkening effect is limited only to the over exposed area. The area becomes transparent again, once the amount of light decreases below the required level. We demonstrate experimental results of the nonlinear operation of the filter under sunlight illumination. Improvement of a security camera's dynamic range is shown by use of the DSF. The DSF element automatically varies its transparency according to the amount of incident light, thus increasing camera's dynamic range.

7660-68, Session 10

Thermally robust IBS coatings for deep concave surfaces

D. C. Ness, C. S. Wood, Precision Photonics Corp. (United States)

Precision Photonics Corporation (PPC) has developed a method of applying Ion Beam Sputtered (IBS) MWIR anti-reflective coatings to the

interior of a tangent Ogive dome. Although IBS has traditionally not been used in this application, it is known that IBS provides the highest density coatings using very hard, durable materials. We achieve a variable coating thickness profile by means of shadow masking coupled with sophisticated 3 dimensional mathematical modeling, which optimizes the antireflection performance over a wide range of look angles for an infrared seeker inside the dome. The coating design for this project survives temperatures up to 1000C.

7660-69, Session 10

Optical coatings for deep concave surfaces

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A method of antireflection coating the interior and exterior surfaces of a deep concave optic is under development and is described. The challenges of coating such an optic include obtaining uniform performance, good mechanical and optical performance across a temperature range of ambient to 1000oC, and the transition to cost effective production. The coating process utilizes a tuned cylindrical magnetron sputtering source which sits inside the nose cone to coat the inner surface and a complementary cylindrical sputtering source to coat the outside surface. The flux from the sputtering source is tuned along the length of the cylinder by stacking an inner core of magnets in such a way as to produce a spatially variant magnetic field which allows the source distribution to approximate a uniform deposition on the surface of the optic. A deposition occulting mask provides fine tuning of source uniformity.

Several magnetron source geometries have been demonstrated. Antireflection coatings were deposited using reactive sputtering. Results are discussed. Plans for production scale up are outlined.

7660-70, Session 10

Development of shutter subsystems for infrared imagers

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Requirements for shutters used in Infrared thermal weapon sight (TWS), thermal vision, and driver vision enhancement (DVE) applications are becoming increasingly more demanding. Requirements include: small size, low weight, low power consumption, shock resistance, wide operating temperature range, high reliability, and low cost. These performance requirements have been achieved using a unique, modular, reconfigurable rotary drive actuator with bi-stability and direct connection to the blade. High-coercivity retention magnets, combined with a thin metal blade operating on hardened pins provides high reliability and shock resistance. A sensing system has been developed to improve reliability by non-optically sensing blade position. A complete set of drive electronics has been incorporated into the shutter to create a "Smart Shutter". The "Smart Shutter" acts as a complete sub-system that can be tested as an integral module. A multi-blade variant has been developed that retains the reliability of the rotary drive system and decreases the physical size of larger-aperture shutters. Low-cost commercial transportation industry infrared vision systems are an important emerging application. Polymeric framed shutters provide a lighter, lower cost alternative to machined aluminum frames. Polymeric frames and polymeric coatings on the blade surfaces create a common emissivity between the frame and one or more blades. This combination of a hardened metal blade and polymeric coating provides high reliability and matched emissivity. Predictions of next-generation application-specific shutter designs will be offered.

7660-71, Session 11

A novel multipixel imaging differential standoff chemical detection sensor

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ABB Bomem is expanding its line of infrared remote sensing products with the addition of a new multi-pixel imaging spectroradiometer. This hyperspectral instrument is based on the proven MR spectroradiometers.

The instrument is modular and support several configurations. One of its configurations is optimised for differential acquisition in the VLWIR (cut-off near 14 µm) to support research related to chemical detection. In that configuration, the instrument is equipped with a dual-input telescope to perform optical background subtraction. The resulting signal is the differential between the spectral radiance entering each input port.

Overview of the design and results from the first field trials will be presented. It will include preliminary results of standoff detection of chemical simulants released in reconnaissance and survey type scenarios.

7660-72, Session 11

Quantum dot infrared photodetectors with highly tunable spectral response for an algorithm-based spectrometer

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We report on low strain quantum dot infrared photodetectors (QDIP) with up to 80 dot in a well (DWELL) stacks. These QDIPs have been grown with lattice matched $Al_{0.1}Ga_{0.9}As$ barriers and GaAs wells allowing a large number of stacks to be grown leading to an increased absorption volume. The QDIPs show a strong spectral response that varies significantly with applied bias, with four distinct peak wavelengths ranging from 5.5µm to 10.0µm. The highly tunable nature of the intrinsic responses makes these QDIPs very attractive as multispectral imagers in the MWIR and LWIR regions. The spectral diversity of these QDIPs has been exploited using an algorithm to produce a highly versatile algorithmic spectrometer. The algorithm assigns a specific weighting factor to each of the intrinsic responses and then sums these weighted responses to achieve any desired spectral shape. Triangular narrowband filters have been synthesised in this way with full width at half maximums (FWHM) as narrow as 0.2µm. The QDIPs can be used to image objects in the MWIR and LWIR regions by measuring the photocurrent generated at each specific bias and summing them using the calculated weighting factors for every wavelength of interest. This technique has been successfully used to reconstruct the radiated power from a blackbody source through IR filters with different centre wavelengths and bandwidths as a function of wavelength in the LWIR and MWIR regions.

7660-73, Session 11

Multispectral UV-Vis-IR imaging using low-cost quantum dot technology

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We will introduce a potentially revolutionary focal plane array technology that would offer the first imaging system for ultraviolet (UV) to short wave infrared (SWIR) wavelengths in a single low-cost sensor array. It would

enable effective day and night imaging without the use of exotic materials or complex multi-camera systems.

The light absorbing layer in the detector is composed of solution processed colloidal quantum dots. Colloidal QDs have received significant attention in recent years for their tunable electrical and optical properties and ease of processing. The ability to tune properties based on particle size allows the development of devices optimized for a particular application. Moreover, these materials continue to absorb through UV and even x-ray energies

RTI has developed a novel photodiode architecture that provides high quantum yield based on colloidal PbS quantum dot (QD) absorber layers. This technology is capable of efficiently detecting light with sensitivity spanning the 250 - 1800 nm spectral region. It is extremely cost effective, solution processable, scalable to large area arrays, and can be applied to flexible substrates. Critical advantages of this technology over traditional InGaAs and InSb technologies includes the simplicity of the structure, ease of fabrication, and its ability to be directly integrated onto a read out integrated circuit, reducing system complexity and cost.

Preliminary measurements show quantum efficiencies of ~55% in these devices at 980 nm. Taking the optical absorbance into account the same devices demonstrated internal quantum efficiency of ~78%, showing that further optimization could lead to substantial gains in efficiency.

7660-74, Session 11

Noise properties of a corner-cube Michelson interferometer LWIR hyperspectral imager

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Interferometric hyperspectral imagers using infrared focal plane array (FPA) sensors have received increasing interest within the field of security and defence. Setups are commonly based upon either the Sagnac or the Michelson configuration, where the former is usually preferred due to its mechanical robustness. However, the Michelson configuration shows advantages in larger FOV due to better vignetting performance and relaxation of beamsplitter specifications due to greater symmetry of the optical paths. Recently, a laboratory prototype of a more robust and easy-to-align corner-cube Michelson hyperspectral imager has been demonstrated. The prototype is based upon an uncooled bolometric FPA in the LWIR (8-14 µm) spectral band and in this paper the noise properties of this hyperspectral imager have been investigated, analyzed and discussed.

7660-75, Session 11

A miniature snapshot multispectral imager

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We present a miniature snapshot multispectral imager that operates in the short wavelength infrared region and has a number of applications. The system is uniquely advantaged where portability demands a miniature platform, low power consumption and very low weight payloads are required. The imager uses a 4x4 filter array operating from 1487nm to 1769 nm with a spectral bandpass of around 10 nm. The design of the filters is based on using a MEMS 23 layer Fabry-Perot etalon. The full size of the filter array is 12.8 mm x 9.6 mm with individual filter size of 3.2 mm x 2.4 mm. The miniature micro lens filter array subsystem is installed in a commercial handheld InGaAs camera and the imaging lens of the camera is replaced by a specially designed 4x4 microlens array with telecentric imaging performance in each of the 16 sub images. The imager was used to acquire a number of different indoor and outdoor scenes. The micro optics and filter design is quite flexible and can be tailored for any wavelength region from UV to Visible to SWIR to LWIR and the spectral bandpass can also be modified

based on the requirements. In this paper we will discuss the design and characterization of the filter bank, the microlens optical package, and the imager and present imaging results obtained.

7660-76, Session 12

Development of miniature, high-frequency pulse tube cryocoolers

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A miniature, high energy density, pulse tube cryocooler with an inertance tube and reservoir has been developed, tested, diagnosed and optimized to provide appropriate cooling for size and power limited cryogenic applications demanding fast cool down. This cryocooler designed using REGEN 3.2 for an operating frequency of 150 Hz and an average pressure of 5.0 MPa, has regenerator dimensions of 4.4 mm inside diameter and 27 mm length and is filled with #635 mesh stainless steel screen. Various design features, such as the use of compact heat exchangers and a miniature linear compressor, resulted in a remarkably compact pulse tube cryocooler. In this report, we present the preliminary test results and the subsequent diagnostic and optimization sequence performed to improve the overall design and operation of the complete cryocooler. These experimentally determined optimal parameters yielded 530 mW of gross cooling power at 120 K with an input electrical power of only 25 W. This study highlights the need to further establish our understanding of miniature, high frequency, pulse tube cryocoolers, not only as a collection of independent subcomponents, but as one single cooling unit. It has also led to additional improvements that may yet be made to even further improve the operating characteristics of such a complete miniature cryocooler.

7660-77, Session 12

Downsized microminiature linear split Stirling cryogenic coolers for high-temperature infrared imagers

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A forthcoming generation of portable, high-definition night vision imagers will rely on the high temperature infrared detectors which are able to operate in the temperature range of 95 - 200K while showing the performance indices comparable with their traditional 77K rivals.

Recent technological advances in industrial development of such high-temperature detectors initialized attempts for developing downsized microminiature cryogenic coolers, both of rotary and linear types, where the linearly driven cryogenic coolers appear to be more suitable for the above electro-optical applications. Their known advantages as compared with their rotary rivals include more flexibility in the system design, inherently longer life time, lower vibration export and aural stealth. Moreover, the latest progress in designing highly efficient "moving magnet" resonant linear drives and accompanied electronics enable further essential reduction of the cooler size, weight and power consumption.

The authors report on the development, project status and attainable performance of a novel Ricor model K527 microminiature split Stirling linear cryogenic cooler. Special attention is paid to resolving cooler induced vibration issues.

7660-78, Session 12

Cryocoolers for infrared missile warning systems

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The growth in world demand for infrared missile warning systems (MWS) originated development of new technologies, in particular, special cryogenic coolers. Since such a cryocooler is a core component in MWS, RICOR has met the challenge by developing new models capable of withstanding high ambient vibration conditions along with temperature extremes in excess of 100°C, as typical for airborne jet fighter applications.

The development focused on cryocooler regenerator and cold finger optimization in order to achieve high cooling capacity and thermodynamic efficiency above 4.5% at 100°C ambient.

In order to withstand harsh environmental vibration, the cold finger and outer Dewar structure have been significantly ruggedized; efficient heat sinking methods have been applied and also novel vibration isolation methods have been implemented.

The electronic design concept is based on an analog controller, the PCB of which has been designed with internal heat sinking paths and special components being able to withstand above temperatures extremes.

As a final stage of development, such cryocoolers were successfully qualified by RICOR in harsh environmental conditions and life demonstration tests were performed.

7660-79, Session 12

The digital onboard drive electronics optimizes the rotary cryocooler functionalities for your demanding applications

J. Martin, Thales Cryogénie S.A. (France)

Thales Cryogenics has a long background in delivering Rotary Monobloc (RM) cryogenic coolers for military and civil programs. More particularly they are very well suited for low acoustic noise applications such as hand-held night vision camera's, soldier infrared equipment and vehicle thermal sight systems. The RM-series includes a range of very compact and lightweight integral coolers, offering several choices in cooling power and has been practice-proven for many years with more than 20.000 units installed worldwide.

This paper will give an overview of technical advantages and benefits of our new onboard digital driver electronics both for the Detectors'Module makers and the End-users. Among others, this electronic can be easily customized, it optimizes the temperature stability, it can be used in a wide range of input voltages and climatic environments, the DSP design allows easy implementation of future additionnal functionalities. These are some capabilities of the novel digital onboard drive electronics available on the new integral IDCA RM3 cooler.

For the next steps, we plan to adapt this onboard drive electronics to the other products of the RM series.

Next to an outstanding Cooler Drive Electronics, the customers also need Easy to use & Easy to replace products. The paper will present how the RM3 can provide user-friendly solutions to these expectations.

7660-80, Session 12

Performance and reliability enhancement of linear coolers

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Highest efficiency seems to be the most important requirement for tactical IR cryocoolers today. For enhancement of thermodynamic efficiency of our linear cooler family a thorough investigation has been performed. All relevant loss mechanisms and associated components within the cooler has been considered. To achieve highest accuracy in predicted performance improvements state-of-the-art simulation tools for magnet circuit of the compressor, Stirling process and the fluid dynamics inside the cooler has been employed. As a result, an improved design for AIM linear coolers has been derived. This Paper gives an overview on the performance enhancement activity and the major results.

A second important requirement for cryocoolers is reliability. AIM has introduced flexure bearing coolers with full Flexure Bearing suspension on both ends of the driving mechanism and Moving Magnet driving mechanism. In conjunction with a Pulse-Tube coldfinger this coolers meeting MTTF's in excess of 50.000h hours. This cooler design also meets the stringent reliability requirements of space applications. In a reliability enhancement program AIM is working on the introduction of technical solution of space coolers into tactical coolers. This Paper will show the status of this reliability program.

7660-81, Session 12

High-reliable linear cryocoolers and miniaturization developments at Thales Cryogenics

H. Van der Weijden, Thales Cryogenics B.V. (Netherlands)

Thales Cryogenics has a long background in delivering linear cryogenic coolers for military, civil and space programs. This cooler range is based on 2 main compressor concepts: close tolerance contact seals (UP) and flexure bearings (LSF) both using Stirling cold fingers. A major difference between these products is the MTTF, which is for the LSF long lifetime coolers far above 20.000 hrs. Since the introduction of the LPT range consisting of a long life flexure bearing compressor equipped with a non wearing pulse tube cold finger, MTTF figures can go up well over 50.000 hours.

During this presentation an overview of general lifetime influencing parameters will be listed versus the impact on the different cooler types like UP, LSF and LPT. Also lifetime test results from both the installed base and the Thales Cryogenic test lab will be presented. In these results the differences between pulse tube and Stirling cold fingers both combined with LSF long life time compressors will be described.

Recent market requirements ask for increasingly more reliable but compact crycoolers for use in the next generation of small sized camera's.

New developments at Thales Cryogenics in answer of these requirements will be presented. We will present 2 new cooler types, which are under development. For these coolers the trade-off between size weight and power with optimum reliability will be described.

In addition new developments for very compact linear cooler drive electronics with high accuracy and power density will be described.

7660-82, Session 13

Operating temperature: a challenge for cooled IR technologies

M. Vuillermet, P. Tribolet, SOFRADIR (France)

Cooled IR technologies are challenged for answering new system needs like the reduction of energy. This reduction is requested in new IR system design in particular for cooled IR detection. The goal is to reduce system sizes, to increase system autonomies and reliabilities and globally to reduce system costs!

One of the key drivers for cooled systems is the cooler and the operating temperature. As far as operating temperature is concerned, Sofradir put a lot of efforts for years for adapting its technologies to increase the operating temperatures of IR detectors. Main examples are dealing with long wave staring arrays based on QWIP technology and on MCT technology as well as medium wave staring arrays using MCT technologies.

7660-83, Session 13

High operating temperature MWIR HDVIP detectors

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The HOT detector is simply a reverse-biased photodiode with minority and majority carrier contacts. The active volume, which is less than a diffusion volume, is in non-equilibrium due to the reverse bias, and the intrinsic thermally generated minority carriers are fully extracted through the minority carrier contacts. The reduction in majority and minority carrier concentrations in the active volume of the HOT device results in a significant reduction in the dark current generation rates in that volume, with the potential for BLIP performance at room temperature.

The detector concept is being pursued using the high density vertically integrated photodiode (HDVIP®) architecture and an n+-p device structure. Dark current densities as low as 2.5 mA/cm2 normalized to a 5 µm cutoff at 250K have been demonstrated on these diodes. These dark currents imply minority carrier lifetimes in excess of 300µsec. 1/f noise in these devices arises from the tunneling of charge into the passivation interface, giving rise to a modulation in the surface positive charge and hence to the width of the depletion region in the p-side of the device and a modulation in the total dark current. The measured 1/f noise is in agreement with the predictions of this model, with very low noise being observed when the lifetimes are high.

Recent work has centered on the application of these structures to 256x256 and 640x480 focal plane arrays. Recent results on these arrays will be presented.

7660-84, Session 13

The performance of MWIR and SWIR HgCdTe-based focal plane arrays at high operating temperatures

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Raytheon Vision Systems (RVS) is producing large format, high definition HgCdTe-based MWIR and SWIR focal plane arrays (FPAs) with 15 µm pitch and smaller for imaging FLIRs, infrared distributed aperture systems, and overhead persistent infrared (OPIR) missions. Infrared sensors made from HgCdTe have singular advantages such as a tunable bandgap, high quantum efficiencies, and R0A approaching theoretical limits. It is desirable to operate infrared sensors at high operating temperatures in order to increase the cooler life and reduce the required system power. However, the sensitivity of many infrared sensors, including those made from HgCdTe, decline significantly above a certain temperature due to the shot noise resulting from the detector dark current.

In this paper we provide performance data on a MWIR focal plane array at temperatures up to 160K and on a SWIR focal plane array at temperatures up to 200K. The FPAs used in the study were both 1536x1024 pixel arrays having a 15 µm pixel pitch. They were indium-bump bonded hybrids of a silicon readout integrated circuit (ROIC) and a HgCdTe detector grown using molecular beam epitaxy (MBE) on a silicon substrate.

The performance data show that the noise equivalent delta temperature (NEDT) is background limited at f/3.4 in the SWIR SCA (cutoff wavelength of 3.7 µm at 110K) up to 150K and in the MWIR SCA (cutoff wavelength of 4.9 µm at 110K) up to 115K.

7660-85, Session 13

Thermo electrically cooled focal plane arrays based on MCT

N. T. Gordon, D. J. Lees, QinetiQ Ltd. (United Kingdom)

One of the main advantages of increasing the operating temperature of infrared focal plane arrays (FPAs) is to take advantage of lower cost cooling options such as thermoelectric coolers. However the maximum cooling available from the current generation of coolers (e.g. 4-stage) is around 110 K. For a maximum operating temperature of 70oC, this means that the FPA needs to operate above 233 K. In this region, the performance becomes a strong function of array temperature and designing a system becomes a trade-off between the performance of the fpa; the speed of the optics; the maximum temperature of operation; and the cooler power and complexity.

In this paper, previous results will be extrapolated to estimate the FPA performance across this trade space by varying cut-off wavelength and operating temperature. Possible techniques to enhance the performance of the FPAs by reducing low frequency noise or adding optical concentrators will also be considered. These extrapolated results indicate that in an f/2 system at 210 K, an NETD of around 30 mK would be achievable and optical concentrators could enhance this further to 18 mK. Potential applications for the technology are in systems where long lifetime; no moving parts; or reduced weight are an advantage. Ideally the maximum ambient temperature should be limited to maintain the best thermal sensitivity. Suitable applications could include sensors which operate from UAVs or in space.

7660-86, Session 13

MWIR InAsSb XBn detectors for high operating temperatures

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The most common background limited MWIR photodiodes operate at cryogenic temperatures, typically in the range 80-120K, where the main dark current mechanism is the generation of carriers at G-R centres in the depletion region of the device. Some years ago, SCD proposed a way to suppress the G-R dark current using heterostructures based on antimonide semiconductor superlattices or alloys. The basic structure, known as an XBn structure, has a band profile similar to that of a standard homojunction p-n diode, except that the depletion region is made from a wide bandgap barrier material with a negligible valence band offset but a large conduction band offset. Here "X" stands for the n- or p-type contact layer, "B", for the n-type, wide bandgap, barrier layer, and "n", for the n-type, narrow bandgap, active layer. The contact layer is designated "X" since it does not have to have the same doping type as the active layer, or be made from the same material. In this work, we report on the fabrication of XBn devices, which were grown by Molecular Beam Epitaxy (MBE) on GaSb substrates. Each structure has an InAsSb active layer of thickness >1.5micron and a 0.2-0.5micron thick AlSbAs barrier layer. The contact layer is either p-type GaSb or n-type InAsSb. High growth uniformity has been achieved with lattice matching of better than 500ppm. Selected layers have been processed into devices which operate with a high internal quantum efficiency at a bias of ~0.1-0.2V, and exhibit a very low dark current which is essentially diffusion limited at all temperatures below 300K. From the dark current measurements, a minority carrier lifetime of >300nS has been estimated. At 150K, and for an active layer thickness >3.5micron, a cut-off wavelength of ~ 4.0 - 4.1 micron is expected in a lattice matched device, with a dark current density in the range ~ 1-3×10-7 A cm-2 and a single pass quantum efficiency of >60%. These figures correspond to BLIP operation at 150K with a photocurrent to dark current ratio of >10 at F/3.

7660-87, Session 13

Mid-wavelength InAsSb detectors based on nBn design

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Sb- based infrared detectors, particularly InAsSb, are important for non-cryogenic thermal imaging applications in the mid wave infrared (MWIR). InAsSb material system can provide cheap, robust and inexpensive infrared detectors as they are based on a mature III-V compound semiconductor technology. Lattice matched InAsSb on GaSb substrate (9% Sb) show excellent material quality for midwave infrared (MWIR) regime. IR detectors using nBn design have recently shown promising results in eliminating the currents associated with Shockley-Read-Hall centers and mesa lateral surface imperfections that increases the operating temperature.

In this paper, we report the design, growth and fabrication of InAsSb detectors based on nBn design by molecular beam epitaxy (MBE). Detailed study of barrier in terms of material, composition and doping level is undertaken, and it is shown barrier design is a key parameter in device performance of nBn devices. Barrier material should be designed with the goal of avoiding any potential depletion region between the barrier and absorbing region as well as blocking the majority carriers and support the flow of minority carriers under applied bias. For this purpose, AlGaSb and AlAsSb are used as the barrier materials and device performance of each barrier is studied. Device simulations are performed using the Sentaurus toolcad software. The simulation results show that signal to noise ratio increases when using AlGaSb barrier as compared to the AlAsSb due to conduction and valence band offset between the absorbing region and the barrier which blocks the electrons and support! s the flow of holes in reaching the contacts, respectively. Optical properties along with growth and simulation results will be discussed in detail in the presentation.

7660-88, Session 13

Spin split-off band-based high operating temperature IR detectors in 3-5 μm and beyond

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The development of uncooled infrared (IR) detectors is crucial for the advancements in various fields including, defense, security, astronomy, and medicine. Split-off (SO) transitions based detector provides a novel alternative to the conventional IR detectors operating at cryogenic temperatures. Recently, a GaAs/AlGaAs split-off detector operating up to 330 K in the 3-5 μm spectral region was developed. This paper presents various design modifications including graded barrier (in place of flat barrier), and double barrier resonant structure (in place of a single barrier) to improve the performance of these detectors. The graded barrier improves the detector performance by reducing the space charge buildup due to trapping at the emitter-barrier interface; additionally, the model implementation on GaAs/AlGaAs based detectors also suggests that a barrier offset of 20 meV approximately doubles the responsivity. The implementation of a double barrier resonant structure increase the escape of holes from the SO to the light/heavy hole bands by bringing the two bands into resonance and increases the response by a factor of ~ 85. In addition to these modifications, the results on the detector performance improvement through plasmonic nanostructures and, the resonant cavity are presented. Plasmonic nanostructures improve the light absorption as a result of Photon-Surface Plasmon coupling. Resonant cavity improves the absorption at the resonant wavelength

due to Fabry-Perot interference between the light beams reflected from top and bottom contacts of the detector structure. The results on the wavelength extension of the SO based detectors using phosphates, and nitrides are also discussed.

7660-89, Session 13

Dark currents, responsivity, and response time in graded gap HgCdTe structures

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The nominally sharp interfaces in layered HgCdTe heterostructures are affected by interdiffusion for growth at temperature above 300ºC. Significant band gap grading always occurs in layered HgCdTe heterostructures grown with MOCVD (350ºC), LPE (480ºC), and especially ISOVPE (500ºC) epitaxial techniques. MBE (170ºC) is the only technique that does not introduce significant interdiffusion effects. The purpose of this paper was to explain how band gap grading effects performance of HgCdTe MWIR and LWIR photodetectors operating at near room temperatures (200-300 K). Influence of composition and doping grading on dark currents, current responsivity, electric capacitance and series resistance was calculated. Initially, numerical simulations were carried out to explain properties of MOCVD devices based on layered heterostructures with relatively sharp interfaces (<0.3 μm) originated from process interface smoothing. Further calculations were carried out for more pronounced purposeful grading. The calculations revealed interesting properties of the graded gap devices. Controlled grading makes possible to reduce dislocation density, minimize dark currents due to the Auger and SR thermal generation, tunneling, increase linearity range. The grading is also essential for high frequency operation reducing capacitance and series resistance. Practical infrared devices based on graded gap structures grown with programmed MOCVD were obtained and characterized.

7660-90, Session 13

Carbon nanotube-based noncryogenic cooled multispectrum focal plane array

N. Xi, Michigan State Univ. (United States)

Middle-wave infrared detection is crucial in various arenas, however traditional middle-wave infrared detectors require bulky cryogenic cooling systems, and they hinder their applications seriously. We have developed carbon nanotube based non-cryogenic cooled multi-spectrum middle-wave infrared detectors that can operate at room temperature. It will explore plenty new applications with this miniature structure.

Carbon nanotube is a perfect one dimensional material. Not only the suppression of phonon scattering inside the carbon nanotube can significantly reduce the dark current of the nanotube based photodetector, but also its high surface to volume ratio will enhance the detection sensitivity, rendering its feasibility to work at room temperature. The band gap of the carbon nanotube depends on its diameter. An electrical breakdown system has been developed to tailor the diameters of a multi-wall carbon nanotube to adjust its detection wavelength precisely. In addition, its structure supports a pixel consisted of several nanotubes, thus a multi-spectrum middle-wave infrared detector can be developed by selecting different band gap nanotubes using the breakdown system.

In order to increase the sensitivity of the detector, we develop the nano-antenna to focus signal externally, and transistor to increase the detection area internally. The nano-antenna creates a resonance structure to boost the electric field intensity at the sensing area. The asymmetric carbon nanotube transistor depresses the dark current and increases the photocurrent by controlling the one dimensional Schottky barrier through

a capacitance coupled gate. The carbon nanotube based detector can be integrated into a focal plane array with higher resolution.

7660-91, Session 13

Performance limits of MWIR III-V ternary and quaternary alloy photodiodes

J. Wrobel, A. Rogalski, Military Univ. of Technology (Poland)

The performance of medium wavelength infrared (MWIR) III-V ternary and quaternary alloy photodiodes are examined theoretically. It is shown that the performance can be explained taking into account thermal generation governed by the Auger and radiative mechanisms. The investigations are carried out for photodiodes operated in a temperature range between 300 and 80 K. The effect of doping profiles on the photodiode parameters (R0A product, I-V characteristic, photoelectrical gain and noise) are considered. It is shown that the theoretical performance of high temperature photodiodes is comparable to that of HgCdTe photodiodes. The theoretical predictions of photodiode parameters are compared with experimental data o

7660-92, Session 13

VPD PbSe technology: the road toward the industrial maturity

M. T. Montojo, R. Linares-Herrero, New Infrared Technologies, Ltd. (Spain); F. Domingo, Univ. Politecnica de Madrid (Spain); A. Baldasano, New Infrared Technologies, Ltd. (Spain)

During the last 15 years, the Spanish MoD laboratories (CIDA) have developed the VPD PbSe technology. The excellent properties of the material (sensitivity in the MWIR band, high performance at room temperature (uncooled), and photodetector) together with a new method of processing the material based on PbSe deposition by phase vapor, fully compatible with Si-CMOS technology, have opened tremendous perspectives with multiple applications for the detector where fast responses and low cost are main requirements.

In 2008 the VPD manufacturing technology was transferred to New Infrared Technologies, S.L. This paper shows the actual situation of the technology, describing the last advances reached with the new 32x32 uncooled imager, able to provide frame rates above 1,000 fps. The work also describes the industrial strategy adopted for bringing the technology towards the industrialization and the roadmap of the technology from the point of view of future devices and systems.

7660-93, Session 14

The critical role of MOVPE technology in delivering highest performance thermal imaging capability

V. Leverett, Finmeccanica U.K. (United Kingdom)

• MCT has traditionally promised the highest performance thermal imaging capabilities
• Until recently, it has proved difficult to deliver those promises
- size and cost and availability of CdZnTe substrates required for growth
- poor material quality
- low yields
• Metal Organic Vapour Phase Epitaxy on GaAs overcomes these problems
- Low cost substrate material
- Readily available from numerous sources
- Large area substrates with many FPA sites per wafer
- High quality MCT growth
- Low defects, high operability
- High yields - many functioning FPAs per wafer
- Heterojunction growth
- Low production costs
• MOVPE removes the major barrier to new FPA formats and designs
- Large area FPAs
- Small pixels
- Complex structures
- High quality diodes
• Recent years have seen a number of new FPAs being developed by Selex Galileo as a result of MOVPE success
- 640x512 arrays of 24um pixels in LWIR
- Compact, low cost 640x512 arrays of 16um pixels in both MWIR & LWIR
- 1024x768 arrays of 16um pixels in MWIR & LWIR
- 640x512 dual waveband (MW/LW) arrays of 24um pixels
- 640x512 dual waveband (MW/LW) arrays of 20um pixels
• Technology now being deployed in systems
- Titan on UK Chinook fleet for Red Illume (uses Albion MWIR "Merlin")
- LST-11 (uses Albion LWIR "Harrier")
- Chameleon (uses Albion LWIR "Harrier")
• MCT now delivering high performance in all infra-red wavebands by virtue of the MOVPE on GaAs process

7660-94, Session 15

Advances in dual-band IRFPAs made from HgCdTe grown by MOVPE

P. Abbott, L. G. Hipwood, C. L. Jones, R. C. Mistry, SELEX GALILEO (United Kingdom)

This paper describes recent advances in the design, fabrication and performance of MW/LW dual-band infrared detectors made from Hg1-xCdxTe (MCT) grown by Metal Organic Vapour Phase Epitaxy (MOVPE). The detectors are staring, focal plane arrays consisting of HgCdTe mesa-diode arrays bump bonded to silicon read-out circuits. Each mesa has one connection to the ROIC and the bands are selected by varying the applied bias.

The MCT mesa diodes are made from an n-p-n heterostructure, such that the compositions of the two n-type absorbers define the cut-off wavelengths of the two bands and the p-type layer acts as a barrier to prevent transistor action. When a bias voltage is applied one junction will be in reverse bias and the other in forward bias. The photocurrent will be from whichever absorber is adjacent to the reverse biased junction, thus switching bias polarity switches the output between bands. The read-out integrated circuit (ROIC) has two capacitors per pixel and the ability to switch bands during a frame giving quasi-simultaneous images. The arrays can also be used in single band mode with improved NETD. Devices made to date have been MWLW but the technology could easily be applied to other waveband combinations such as LW1/LW2 or MW1/MW2.

The mesa diodes are formed by a combination of dry and wet etching and this process has been developed to the point where 14 μm deep mesa slots on a 20 μm pitch are practical. Modifications to the MCT heterostructure design have improved the quantum efficiency, operability, and signal uniformity, and reduced spectral cross-talk. Typical performance parameters for MW/LW 640x512 arrays on a 24 μm pitch measured in f/2 are: operability 99.8% in the MW and 99.6% in the LW band, quantum efficiency 80% in the MW and 66% in the LW band. Interestingly the LW and MW defects are not correlated; i.e. a pixel that is defective in the MW band may not be defective in the LW band. Spectral cross-talk, defined as the percentage of the LW response to a black body spectrum that can be attributed to MW photons, is ~ 0.4% for a 300 K

black-body. On a 20 µm pitch the operability is slightly worse in the MW at 99.1% but the other parameters are unchanged.

The possibility of further reduction in pitch will be discussed.

7660-95, Session 15

MCT IR detectors: trends and developments in France

G. L. Destéfanis, CEA-LETI MINATEC (France); P. Tribolet, SOFRADIR (France)

In this paper we present the new trends and developments in France at LETI and SOFRADIR of the research and development of IR detectors based on MCT materials.

This includes activities and choices in CdZnTe bulk crystal growth for substrate and MCT epitaxial growth by MBE or LPE. A focus will be made on the planar technology evolution for diode formation from n on p to p on n diode.

A review of our recent activity on single color large 2D FPAs that operate from SWIR to VLWIR (including the visible) will be made. A special attention will be given to the problem linked to the possibility to operate the FPA at low flux.

The problem of cost reduction will also be considered thought two different aspects: pitch reduction that allows more compact FPAs to be made or/and higher operating temperature that allows reducing the cost of the cooling system.

The 3rd generation detector activity evolution will also be considered from multicolor FPAs to APD FPAs for active imaging and our last results will be given.

The last point of this paper will be focused on our activity on the 4th generation that includes optical functions in the FPA.

7660-96, Session 15

Wide-band (2.5 - 10.5 µm), high-frame rate IRFPAs based on high-operability MCT on silicon

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We have previously presented results from our mercury cadmium telluride (MCT, Hg1-xCdxTe) growth on silicon substrate technology for different applications, including negative luminescence, long waveband and mid/long dual waveband infrared imaging. In this paper, we review recent developments in QinetiQ's combined molecular beam epitaxy (MBE) and metal-organic vapor phase epitaxy (MOVPE) MCT growth on silicon; including MCT defect density, uniformity and reproducibility. We also present a new small-format (128 x 128) focal plane array (FPA) for high frame-rate applications including spectroscopic and time dependent imaging.

A custom high-speed readout integrated circuit (ROIC) was developed with a large pitch and large charge storage aimed at producing a very high performance FPA (NETD < 10mK) operating at frame rates up to 2kHz. A broadband (2.5-10.5 µm) MCT heterostructure was designed and grown by the MBE/MOVPE technique on silicon substrates. FPAs were fabricated using our standard techniques; wet-etched mesa diodes passivated with epitaxial CdTe and flip-chip bonded to the ROIC.

The resulting focal plane arrays were characterized at the maximum frame rate and shown to have high operabilities and low NETD values, which is characteristic of our LWIR MCT on silicon technology.

7660-97, Session 15

Recent results of two-dimensional LW- and VLW-HgCdTe IR FPAs at AIM

J. Ziegler, D. Eich, S. Hanna, J. Wenisch, A. Bauer, H. Bitterlich, M. Bruder, K. Mahlein, H. Lutz, R. Wollrab, AIM INFRAROT-MODULE GmbH (Germany)

The operational need for light-weight, compact low cost IR-modules with minimum power consumption has continuously been growing. To match such requirement, AIM started 2007 the development of a MCT 640x512 IR-detector with 15 µm x 15 µm pitch. While 3-5µm detectors cover many standard requirements, the gold standard for critical military missions is still the 8-10µm window. For this spectral range, however, the material growth of the epitaxial MCT layer and the subsequent array processing is much more critical with respect to homogeneity, number of defective pixels and linearity under high illumination conditions. The relevant material and array processes, the progress in development, as well as results from CMT 640x512, 15 µm pitch IR-modules, sensitive in the LWIR will be presented.

For spaceborne commercial satellite systems such as the Meteosat Third Generation (MTG) program, AIM develops MCT based 2D very long wavelength (VLWIR) detector arrays with a cut-off wavelength > 14 µm. In order to achieve both high radiometric as well as high imaging performance, cryogenically cooled photovoltaic MCT detectors are preferred candidates for 2D arrays. They offer highest quantum efficiency and a low power dissipation. However, since the dark current of photodiodes increases exponentially with increasing cut-off wavelength, the operating temperatures of such MCT PV are typically 50 - 60 K. For the AIM standard n-on-p technology on LPE-grown MCT, the low dark current required could not be achieved using standard Hg-vacancy p-doping due to Shockley-Read recombination processes. Extrinsic doping was applied instead, resulting in a significant decrease in dark current by more than an order of magnitude. This allows for excellent performance in the VLWIR at operating temperatures of 50 K - 60 K. AIM presents its latest results on extrinsically p-doped (256x256) VLWIR MCT-photodiode arrays with a cut-off wavelength > 14 µm.

7660-98, Session 15

MCT IR detection modules with 15 µm pitch for high-reliability applications

R. Breiter, J. C. Wendler, H. Lutz, S. Rutzinger, T. Ihle, K. C. Hofmann, J. Ziegler, AIM INFRAROT-MODULE GmbH (Germany)

Additional to the development of 3rd Gen IR modules like dual-band and dual-color devices AIM is focused on IR FPAs with reduced pitch. These FPAs allow to build up compact low cost IR modules with minimum power consumption for state-of-the-art high performance IR systems.

AIM has realized full TV format MCT 640x512 mid-wave and long-wave IR detection modules with a 15µm pitch to meet the requirements of critical military applications like thermal weapon sights or FLIRs in UAV applications. In typical configurations like a F/4.6 cold shield for the 640x512 MWIR module an NETD < 25 mK @ 5 ms integration time is achieved, while the LWIR module achives an NETD < 30 mK @ F/2 and 110µs integration time. For the LWIR modules FPAs with an cut-off of 10µm have been realized. The modules are available either with different integral rotary cooler configurations for portable applications which require minimum cooling power or a split linear cooler with a flexure bearing compressor providing long lifetime with a MTTF >20,000h as required e.g. for warning sensors in 24/7 operation.

The modules are available with an optional image processing electronics providing non-uniformity correction and further image processing for a complete IR imaging solution. A dual field of view FLIR for an upgrade of the German Army UAV LUNA has been developed by AIM using the MCT 640x512 MWIR 15µm pitch engine.

The paper will present the latest results and performance of those modules and the applications using them.

7660-99, Session 16

Low IR input flux condition operations thanks to MCT e-APD

F. P. Pistone, P. Tribolet, M. Vuillermet, SOFRADIR (France)

Low IR input flux conditions are answering different system applications as gas detection needs, active imagery, very long ranges detection and identification and some scientific applications. Then for other applications like ground applications, some system design trade-off could be made between thermal performance and identification and equipment size and cost.

In all of these cases, MCT e-APD are the optimum solutions to answer these needs. Last technological and products achievements are presented outlining the possible uses of avalanche photodiodes.

7660-100, Session 16

Developments in HgCdTe avalanche photodiode technology and applications

A. P. Ashcroft, I. M. Baker, SELEX GALILEO (United Kingdom)

SELEX Galileo has developed avalanche photodiode technology in HgCdTe to serve a whole range of applications in defence, security, commercial and space research. Burst-illumination LIDAR (BIL), using a near-infrared pulse laser and a fast, gated detector, is now adopted for most long range imaging applications. New results from range trials using prototype systems based on multifunctional and 3D detectors will be reported. In the astronomy field ADP arrays at 2.5 μm cutoff can provide near-single photon sensitivity for future wavefront sensors and interferometric applications. Under a contract from European Southern Observatories arrays have been successfully demonstrated with gains up to 20x and negligible dark current at 77K. Under a European Space Agency contract, a large area, single element detector has been designed for the 2.015μm CO_2 absorption line. The sensor is specifically designed to be operated at 200K so that thermoelectric cooling is viable. The element is made up of many sub-pixel diodes each deselectable to ensure high breakdown in the macro-pixel. The latest results of the detector and its associated transimpedance amplifier (TIA) will be presented.

7660-101, Session 16

HgCdTe-based APD focal plane array for 2D and 3D active imaging: first results on a 320 x 256 with 30 μm pitch demonstrator

E. De Borniol, F. Guellec, J. Zanatta, J. Rothman, M. Tchagaspanian, P. Castelein, G. L. Destéfanis, Commissariat à l'Énergie Atomique (France); J. Peyrard, Délégation Générale pour l'Armement (France)

After a first demonstration on a 10x10 pixels FPA, CEA-Leti has developed a 320x256 FPA for 2D and 3D active imaging based on flash LADAR technology. The readout IC (ROIC) has been designed in a standard 0.18μm CMOS process and performs time-of-flight measurement in addition to 2D intensity imaging with a single emitted laser pulse. This ROIC has been hybridized to a 30 μm pitch MWIR n/p avalanche photodiode (APD) array using our in-house HgCdTe process. The experimental setup used to test the FPA and the first 2D active imaging performance assessment will be presented. Main figure of merit of the APD array will also be detailed in this paper.

7660-102, Session 16

Single-photon imaging camera development for night vision

S. A. Vasile, aPeak, Inc. (United States); J. Cheng, Massachusetts Institute of Technology (United States); J. Lipson, aPeak, Inc. (United States); J. Michel, Massachusetts Institute of Technology (United States)

Single-photon imaging in infrared will add a new valuable tool to night imaging applications. Despite years of development, SWIR cameras are still expensive and not ready for large-volume production. Germanium (Ge) is a promising semiconductor to convert SWIR radiation and has seen extensive development in conjunction with high-speed optical communications. Previous research on Ge/Si, has demonstrated quantum efficiency >80% from 1000 nm to 1550 nm.

Apeak Inc. is developing a new low-light level infrared array technology based on the single-photon sensitive Geiger avalanche Photodiode (Si-GPD) array technology and the development of low-dislocation Germanium. The core of the imaging camera is a Ge:Si photon-counting GPD pixel with CMOS readout. The primary technology objective is to demonstrate through prototyping and semiconductor process development the technical feasibility of low-cost, single-photon detection cameras sensitive in the VIS-SWIR. We report on the first prototype Ge:Si structures compatible with the GPD operation and technology. We demonstrated on these structures 33% quantum efficiency at 1310nm and predict $3x10^7$photons/cm2 x sec intrinsic sensitivity at 60K. As the GPD output is binary and the camera operates in photon-counting mode, a digital readout has been developed to provide adjustable dynamic range and frame rate. As the GPD technology has excellent gating and ranging capability, the pixel architecture is being developed with the secondary technology objective to allow both passive two-dimensional imaging and active illumination three-dimensional imaging.

This technology development responds to the Army's objective of fusing image intensification with infrared technologies to rapidly meet the warfighter's protection in the new combat conditions.

7660-103, Session 16

Single-photon ranging RCE FPA in NIR

S. A. Vasile, J. Lipson, aPeak, Inc. (United States); S. M. Unlu, Boston Univ. (United States)

Active illumination with gated, fast, infrared enhanced sensors will allow developing Focal Plane Arrays (FPA) for three-dimensional imaging and high bandwidth laser communications in the near infrared (NIR). Silicon Geiger avalanche Photodiode (GPD) arrays have proved excellent timing resolution and single photon sensitivity in the visible spectral range. As silicon has weak absorption at 1064nm, one elegant approach to increasing its absorption efficiency is to trap the photons inside the silicon using the resonant cavity enhancement (RCE) effect.

We present in this paper the GPD pixel technology developed at aPeak that combines the advantages of the silicon GPD with the resonant cavity technology to yield FPA for single-photon detection, as well as the development of smart pixel readouts with fast response and time stamp memory to be implemented into such photon-counting detector arrays. Integration of readout with GPD sensors and RCE required process flow modification only at the back end and allowed capitalizing on the existing silicon GPD technology and smart pixel designs specifically developed for GPD operation. We have demonstrated that large FPAs are feasible, provided that suitable process control protocols are developed. We report a 10X performance enhancement at 1060 nm of the resonant cavity GPD prototypes, less than 150ps timing jitter in single photon mode and less than 20ps jitter for multi-photon hits.

7660-104, Session 16

Development of low-noise and high-speed SWIR photo receivers

X. Bai, P. Yuan, P. A. McDonald, J. C. Boisvert, J. J. Chang, W. D. Hong, R. Sudharsanan, Spectrolab, Inc. (United States); W. Lu, G. Yang, X. Sun, M. A. Krainak, NASA Goddard Space Flight Ctr. (United States)

In this presentation, we will discuss our efforts to develop a 1 GHz photo receiver with a NEP of 300 fW/rt(Hz). The Impact Ionization Engineering (I2E) structure is employed to reduce the APD excess noise factor. Low noise transimpedeance amplifiers (TIAs) are carefully integrated with our low noise APDs to realize high performance photo receivers.

7660-105, Session 16

High-gain high-sensitivity resonant Ge/Si APD photodetectors

J. E. Bowers, D. Dai, Univ. of California, Santa Barbara (United States); Y. Kang, M. T. Morse, Intel Corp. (United States)

We are investigating high gain Ge/Si APD photodetectors that utilize the small k factor in silicon for large gain bandwidths products and low noise in APDs. The highest measured GBP is 860 GHz at -30 dBm in normal incidence operation. We describe the effect of impact ionization on the impedance of the diode and how that can be utilized to resonant the diode capacitance and increase the gain bandwidth product of the APD. Uniformity of low dark current APDs across the 200 mm diameter wafer will be discussed along with applications to SWIR imaging.

7660-158, Session 16

Advances in HgCdTe APDs and LADAR receivers

M. D. Jack, Raytheon Vision Systems (United States)

Raytheon is developing NIR sensor chip assemblies (SCAs) for scanning and staring 3D LADAR systems. High sensitivity is obtained by integrating high performance detectors with gain i.e. APDs with very low noise Readout Integrated Circuits. Unique aspects of these designs include: independent acquisition (non-gated) of pulse returns, multiple pulse returns with both time and intensity reported to enable full 3D reconstruction of the image. Recent breakthrough in device design has resulted in HgCdTe APDs operating at 300K with essentially no excess noise to gains in excess of 100, low NEP <1nW and GHz bandwidths and have demonstrated linear mode photon counting. SCAs utilizing these high peformance APDs have been integrated and demonstrated excellent spatial and range resolution and 3D imagery both at short range and long ranges. In this presentation we will review progress in high resolution scanning, staring and ultra-high sensitivity photon counting LADAR sensors.

7660-125, Poster Session

Analysis of background irradiation in thermal IR hyperspectral imaging systems

W. Xu, J. Wang, Shanghai Institute of Technical Physics (China)

In this paper our group designed a thermal IR hyper-spectral imaging system installed in a vacuum cavity with temperature controlling equipments. The spectral resolution is 80 nm; the spatial resolution is 1.0 mrad; and the spectral channels are 32. By comparing and verifying the theoretical simulated calculation and experimental results for this system, we obtained the precise relationship between the temperature and background irradiation of optical and mechanical construction, and found the most significant components in the optic path for improving imaging quality that should be traded especially, also we had a conclusion that it should cool the temperature of imaging optics and structure down to about 100K if we need utilize the full dynamic range and capture high quality of imagery

7660-126, Poster Session

Performance of the SITP 35K two-stage Stirling cryocooler

D. Liu, A. Li, S. Li, Y. Wu, Shanghai Institute of Technical Physics (China)

This paper describes the development and performance of a long-life, two-stage stirling cryocooler. The cooler is designed to provide 0.5w cooling power at 35K for very long wavelength infrared detectors. The two-stage stirling cold head is driven by a linear flexure bearing compressor with moving coil. Performance experiments have been performed as a function of compressor and displacer strokes, phase angles, and heat sink temperature over an assortment of mid-stage and cold-stage temperatures from 35 to 100 K. The experimental results have shown 0.5 w of cooling power at 35K for 60w of compressor input power. The cooler is undergoing environmental testing that includes thermal vacuum testing and vibration testing.

7660-127, Poster Session

Effects of absorption layer characteristic on spectral photoresponse of mid-wavelength InSb photodiodes

W. Hu, X. Chen, W. Lu, Shanghai Institute of Technical Physics (China)

In this paper, we report on 2D numerical simulations of photoresponse characteristic for mid-wavelength InSb infrared photodiodes. For plain drift-diffusion simulation the well known Poisson equation and continuity equations are used. The carrier generation-recombination process consists of Shockley-Read-Hall, Auger, and optical generation-recombination terms. Additionally, tunneling effects, such as band-to-band and trap-assisted tunneling models, are included in the continuity equations by representing them as additional generation-recombination processes. Effects of thickness of absorption layer on the photoresponse have been investigated for both front-side and back-side illuminated devices. Optimal thickness of absorption layers at different diffusion lengths are extracted numerically.

Our theoretical work shows that the optimal thicknesses of absorption layers can be strongly affected by the wavelengths of incident light and minority carrier lifetimes. An empirical formula is proposed to predict a reasonable optimal thickness of absorption layer by numerically analyzing its correlations with the absorption lengths and diffusion lengths.

7660-128, Poster Session

Infrared search and track system based on dual-band 1D sensors

S. Nam, B. Choi, S. Joung, J. Youn, Samsung Thales Co., Ltd. (Korea, Republic of)

In the maritime environment, IRST system which searches and tracks the approaching targets can be necessary for the ship's self protection. Agency for Defense Development (ADD) and Samsung Thales developed the high performance IRST system based on dual band 1-D IR sensor. Our IRST system can obtain high performance as using several FPGA and COTS processing boards. Dual band IR sensor (MWIR and LWIR)

also can give the two types of target detection and tracking abilities. Therefore our IRST system can automatically detect and track both air and surface targets such as sea skimming missiles, small ships, and aircrafts at a long range. In this paper, we briefly describe technologies in our developed IRST system such as dual band 1-D sensor, optical design, hardware architecture for signal processing. We detail describe software architecture for signal processing and target detection and tracking algorithms for high performance as well.

7660-129, Poster Session

Radiation hardening of low-noise readout integrated circuit for infrared focal plane arrays

M. S. Lee, Y. S. Lee, H. C. Lee, Korea Advanced Institute of Science and Technology (Korea, Republic of)

To improve the reliability of infrared image systems operating at radiative environment such as in space or in a nuclear reactor, we have studied the radiation resistant readout integrated circuit for focal plane arrays. The radiation hardened N-MOSFET structure including the layout modification technique is proposed and simulated with Silvaco ATLAS-3D simulation tool. By using the simulated results of the proposed N-MOSFET, we designed readout integrated circuit for infrared focal plane arrays. The proposed unit N-MOSFET and designed readout integrated circuit adopting proposed N-MOSFET were fabricated via the commercial 0.35um process. The electrical characteristics of the fabricated unit N-MOSFET are measured by HP 4156A equipment. The performance of designed readout integrated circuit is verified by FPGA based control circuit and oscilloscope. The electrical characteristic of the fabricated unit N-MOSFET and readout integrated circuit were well matched with the previously simulated results. To verify radiation tolerance, the fabricated chip were exposed to 1Mrad(Si) gamma radiation which is enough high to guarantee the reliability for using in space or very harsh radiation environment. While exposure to gamma radiation, the chip was connected to power supply(3.3V) for testing at worst condition. After being exposed to 1Mrad gamma radiation, the unit N-MOSFET shows little increment of a few pico-ampere leakage current and designed readout integrated circuit shows little change at output voltage below than 10%. That changes of unit N-MOSFET characteristics and designed readout infrared integrated circuit are allowable value when compare to process variation.

7660-131, Poster Session

Development of a miniature coaxial pulse tube cryocooler for a space-borne infrared detector system

H. Dang, Y. Wu, L. Wang, K. Yang, W. Shen, Shanghai Institute of Technical Physics (China)

Shanghai Institute of Technical Physics, Chinese Academy of Sciences (SIPT/CAS) is developing a single-stage miniature coaxial pulse tube cryocooler to provide reliable low-noise cooling for an infrared detector system to be equipped in the future space mission. The required cooling capacity is 1.6-2.0W@90K, and the more challenging work is the exacting requirement on its dimensions, which have to adapt to the prescribed Dewar. The cold finger has an effective length of about 64 mm with an outer diameter of 10 mm. The limited dimensions result in the insufficiency of the phase-shifting ability of the system when the inertance tube alone is employed. A second-inlet flow impedance component is thus introduced in order to obtain, together with the inertance tube, a better phase relationship between the pressure and mass flow of the oscillating working gas. The second-inlet impedance component is fabricated into asymmetric to eliminate the potential DC flow phenomenon. A larger filling pressure of 3.5 Mpa and higher operating frequency of up to 70 Hz are adopted to increase the energy density, which will compensate for the decrease in working gas volume

due to the miniature structure, and realize a fast cool down process. A 1.5 kg dual opposed linear compressor is used to generate oscillating pressure wave, which is based on flexure bearing and moving magnet technology and developed in the same group to realize light weight, high efficiency and low contamination. This paper describes the design approach and trade-offs. The cooler performance and characteristics will also be presented.

7660-132, Poster Session

Development of high-capacity U-type pulse tube cryocoolers for a cold optics system in space applications

H. Dang, Y. Wu, L. Wang, Shanghai Institute of Technical Physics (China); K. Yang, Shanghai Institute of Technical Physics (Chile); W. Shen, Shanghai Institute of Technical Physics (China)

Shanghai Institute of Technical Physics, Chinese Academy of Sciences (SIPT/CAS) is developing a large cooling capacity U-type pulse tube cryocoolers in order to replace the heavy and cumbersome passive radiator system to provide cooling for the cold optics system, which is a component part of a sophisticated infrared sensors system used in a specific weather satellite. The pulse tube cold finger is chosen because its acceptable low noise level, higher refrigeration efficiency and smaller size and weight compared with the present system. Due to the installation interface provides enough room, so the U-type other than coaxial arrangement is adopted to obtain a robust and simple system. The U-type cold finger also avoids the potential loss introduced by the possible mismatch of the temperature profiles of pulse tube and regenerator, and thus has a higher refrigeration efficiency compared with its coaxial rival. The cooler is designed to lift over 8.0W of heat at 150K and the overall weight is less than 12 kg, which is powered by a split dual opposed piston compressor with a maximum swept volume of 7.5 cc. Besides the conventional integral "U"-shaped cold tip, a novel detachable two-half cold head is designed to enhance cooling performance. Some fine grooves are engraved in the upper part of the novel cold head using electro discharge machining technology, which can not only increase the heat transfer area, but also serve as a straightener for the turbulence introduced by the flow reversal. The design considers, experimental results, and performance analyses are presented.

7660-133, Poster Session

Development of a 2.0W/60K single-stage coaxial pulse tube cryocooler for long-wave infrared focal plane array applications

H. Dang, Y. Wu, L. Wang, K. Yang, W. Shen, Shanghai Institute of Technical Physics (China)

A 2.0W@60K single-stage coaxial pulse tube cryocooler has been developing in Shanghai Institute of Technical Physics, Chinese Academy of Sciences (SIPT/CAS). The goal is to provide reliable low-vibration cooling for the space-borne Long Wave Infrared Focal Plane Array (LWIRFPA) with an electric input power of less than 100 W and a 300K reject temperature. The coaxial configuration result in a compact system and the outer diameter of the cold finger is about 20 mm. The inertance tube together with a gas reservoir serves as the only phase-shifting component in order to obtain a highly reliable system. The inertance tube consists of two parts with different inner diameter and length to obtain desirable phase relationship. Both cold tip and warm flange integrated with fine slit heat exchanges fabricated with electro discharge machining technology to enhance heat exchange performance. The cooler system adopts split arrangement and an Oxford-type linear compressor with dual-opposed piston configuration is connected to the cold finger with a 20 mm flexible metallic tube. The overall weight including cooler control electronics is controlled below 10 kg. The design and optimization of the cooler are based on the theoretical CFD model developed by the analyses of thermodynamic behaviors of gas parcels in the oscillating

flow. The well-known regenerator simulation software REGEN and machine model SAGE are also employed to make verification and further optimization. The system design is described by focusing on the thermodynamic aspects, and the cooler performance is investigated and evaluated.

7660-134, Poster Session

Development of space Stirling and pulse tube cryocoolers in Shanghai Institute Technical Physics, Chinese Academy of Sciences

Y. Wu, H. Dang, Shanghai Institute of Technical Physics (China)

This paper reviews the development of space Stirling and pulse tube cryocoolers in Shanghai Institute Technical Physics, Chinese Academy of Sciences (SIPT/CAS). SITP/CAS has a more than 20-year history in studying and delivering Stirling cryocooler for space-borne infrared applications. It covers from 30 to 100K and involve single and double stages. Typical cooling capacity includes 1.0W@35K, 2.5W@60K, 2.0W@80K and 6.0W@90K when electric input powers are below 80 W, and can provide effective cooling for HgCdTe based IR detectors from near visible down to long wave region. Both moving coil and moving magnet linear compressors are developed. The swept volume varies from 2 cc to 8 cc and input power reaches up to 150 W. Lightweight coolers have lowered to 2.5 kg, and advanced control electronics and adaptive active vibration control technology are becoming mature.

Research on the high efficiency Stirling-type pulse tube cryocooler is a rising domain in SITP/CAS in recent years. Its attractive merits such as further lower vibration cold fingers and potential longer lifetime are making it become our next research focus. At present the single-stage coolers cover from 60 to 150K and typical cooling capacity includes 2.0W@60K, 5.0W@80K and 8.0W@150K. The various phase-shifting approaches to obtain high COP and the measures to realize lower vibrations and lighter weights are emphasized.

This paper outlines the status of both types of coolers, including those currently undergoing performance optimization, qualification investigation, or characterization and endurance evaluation. The performance comparisons and efforts to increase reliability are also presented.

7660-135, Poster Session

Design of a ROIC for scanning type HgCdTe LWIR focal plane arrays

H. Kayahan, Y. Gurbuz, M. Yazici, O. Ceylan, Sabanci Univ. (Turkey)

Design of a silicon readout integrated circuit (ROIC) for HgCdTe Focal Plane Arrays of size3x7 intended for LWIR operation region is presented. The design is a small scale circuit for a 576x7 scanning type cooled imaging system. ROIC incorporates time delay integration functionality over seven elements with a super sampling rate of three, increasing SNR and the spatial resolution. ROIC, in terms o functionality, is capable of bidirectional scan, dead pixel deselection and automatic gain adjustment in presence of a dead pixel, programmable integration time and 5 different gain settings at the input. Programming can be done parallel or serially with pixel deselction capability being limited to serial programming. ROIC can handle up to 4.5 million electrons at the integration capacitor (corresponding to a 3.75V dynamic range) with the input stage to be direct injection (DI) type. With the load being 10pF capacitive in parallel with 1MΩ resistance, output settling time is less than 100nsec enabling the clock frequency up to 5MHz. Input referred noise is less than 1000 electron rms. The manufacturing technology is 0.35μm, double poly-Si,four-metal 5V CMOS process.

7660-136, Poster Session

The radiation tolerance of chalcogenide glasses

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Chalcogenide glasses are glasses compounded from chalcogen element (16th group of element), for example sulphur, selenium, and tellurium. These glasses are applied to commercial applications such as night vision, because they transmit infrared in the spectral range of 0.8-16um. Chalcogenide glasses have great advantages compared to germanium (Ge). Those are the wide spectral range of high transmissivity and the small temperature dependence of refractive index.

We have worked on development the Compact Infrared Camera (CIRC) with an uncooled infrared array detector (microbolometer) for space application. We schedule to launch the CIRC in 2013 to demonstrate the usability of microbolometer as space application. The optics of the CIRC adopts two different kinds of materials for athermal optics. One is the Ge, and the other is GASIR1 which is chalcogenide glass (Ge22As20Se58) developed by Umicore. But the radiaion tolerance of GASIR have not investigated in the past.

We carried out the irradiation test in order to investigate the radiation tolerance of GASIR1. We irradiated GASIR1 with gamma-ray (Co60, 1.17MeV, 1.33MeV) up to 3Mrad. We measured the transmissivity and refractive index in the infrared range before and after irradiation. And we carried out the same irradiation test to different kinds of materials for comparing with GASIR, ZnSe and Ge, too. In this paper, we report the results of the irradiation test of GASIR1.

7660-137, Poster Session

Property of reactively sputtered nickel oxide films as a microbolometer sensing material

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For last several decades, many bolometric sensing materials have been developed for micro-bolometer application. Only vanadium oxide and amorphous silicon were successfully developed for commercialized micro-bolometer. But, many studies are still investigated for new bolometric sensing material , which is easy to fabricate, have a good performance and a low-cost.

In this study, we have investigated the feasibility of a reactively sputtered thin nickel oxide film for micro-bolometer application. Using 4156A parameter analyzer included TEC temperature controller, spectrum analyzer and low noise amplifier, the systemic analysis of electrical and noise characteristic of patterned nickel oxide film is performed , respectively. The properties of a developed thin nickel oxide film can be changed by the condition of sputter process parameter. The measured resistivity of nickel oxide was range from 0.2 Ωcm to 33 Ωcm. Temperature coefficient of resistance (TCR) value of range of -1.4%/ to -3.3%/ was acquired. 1/f noise characteristic obtained in our study was comparable to that of a-Si.

Thus, the thin nickel oxide, which is CMOS compatible and yields high TCR and good 1/f noise, has a good prospect for micro-bolometric material.

7660-138, Poster Session

Noise processes modeling in HgCdTe infrared photodiode detectors

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A numerical model of the current noise spectral density in elements of infrared focal plane array based on HgCdTe photodiodes has been developed. Model is based on Langevine's method and applied to the photodiode structure with p+-n-junction and base of finite length d. Dominated dark current diffusion mechanism typical for high-quality photodiodes and random nature of generation-recombination and scattering processes determined the diffusion current fluctuations has been taken into account. The model main peculiar properties are the stochastic boundary conditions on the interface between depletion and quasi-neutral diode regions proved to be true for small biases of all polarities and wide frequency band tfl << 1, where tfl. is the minority carriers flight time through the depletion region, determined the model applicability domain. Current noise spectral density evaluation of diode element with short base d < Lp, where Lp is the minority curriers diffusion length, was made by exact numerical solution of ambipolar stochastic differential Langevine's equation using computer algebra methods. At noticeable reverse junction biases $|qV| > 3kT$ in diodes with blocking contact to substrate, in which recombination velocity S = 0, the diffusion current noise suppression in whole frequency band tfl << 1 is to be observed, for all that the diffusion current noise spectral density is less than in diodes with long base (d ∞) by a factor th(d/Lp). At slight biases $|qV| < 3kT$ the diffusion current noise suppression occurs only in limited frequency band < 1, where is the minority carriers lifetime, while at high frequencies >> 1 diffusion current noise comes out of scattering processes fluctuations and is independent on the diode structure. Photocurrent noise spectral density for ohmic and blocking contacts to substrate has been calculated too.

7660-139, Poster Session

Fabrication of wavelength selective germanium dielectric supported microbolometers

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This paper describes the microfabrication process and characterization of wavelength selective germanium dielectric supported microbolometers, which should be compatible with standard microbolometer microfabrication processes. The spectral behavior of these devices is essentially that of Salisbury screen or Jaumann absorber, normally used as broad band electromagnetic absorbers. However, several other approaches for producing wavelength selective devices for use in long-wave infrared (LWIR, 8-12μm) focal plane arrays have been previously discussed. Here we use dielectric coated Salisbury screen to achieve narrow band IR absorption. The fabricated microbolometers consist of a chromium resistive sheet as an absorber layer above an air-gap/germanium dielectric structure. The absorbance is mainly controlled by the sheet resistance of the absorbing thin film and by the thickness of the air gap and dielectric layer. Reasonably narrow band response is achieved using a half wavelength air gap and a quarter wavelength dielectric support layer. Usually silicon nitride is used as the structural layer in microbolometers. Here we use instead germanium as a structural layer above a polyimide sacrificial layer. The main advantage of using only Ge as both the interference layer for wavelength selectivity in the dielectric coated Salisbury screen and the structural layer is electromagnetic improvement since this eliminates the highly absorbing and dispersive silicon nitride layer. We have found that the robustness of the Ge layer during oxygen plasma removal of the polyimide is adequate

for good LWIR spectral performance.

7660-140, Poster Session

The calibration stand for thermal camera module with infrared focal plane array

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In areas like military systems, surveillance systems, or industrial process control, more and more often there is a need to operate in limited visibility conditions or even in complete darkness. In such conditions vision systems can benefit by using thermal vision cameras. In thermal imaging an infrared radiation detector arrays are used. Contemporary infrared detector arrays suffers from technological imprecision which causes that the response to uniform radiation results in nonuniform image with superimposed fixed pattern noise (FPN). In order to compensate this noise there is a need to evaluate detectors characteristics like responsivity and offset of every detector in array. The paper presents the design of infrared detector array measurement stand allowing measurement of mentioned parameters. Measurement stand was also used to evaluate temporal noise of infrared detection modules. In article there is a description of optical system design and parameters of used reference blackbodies. To capture images from camera modules a specially designed digital image interface was used. Measurement control and calculations were made in specially written software.

Stand was used to measure parameters for cameras based on uncooled focal plane arrays from ULIS and cooled focal plane arrays from Sofradir. Results of two-point nonuniformity correction of every array and temporal noise evaluation are also presented.

7660-141, Poster Session

Adaptable infrared image processing module implemented in FPGA

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Rapid development of infrared detector arrays caused a need to develop robust signal processing chain able to perform operations on infrared image in real-time. Every infrared detector array suffers from so-called nonuniformity, which has to be digitally compensated by the internal circuits of the camera. Digital circuit also has to detect and replace signal from damaged detectors. At the end the image has to be prepared for display on external display unit. For the best comfort of viewing the delay between registering the infrared image and displaying it should be as short as possible. That is why the image processing has to be done with minimum latency. This demand enforces to use special processing techniques like pipelining and parallel processing.

Designed infrared processing module is able to perform standard operations on infrared image with very low latency. Additionally modular design and defined data bus allows easy expansion of the signal processing chain. Presented image processing module was used in two camera designs based on uncooled microbolometric detector array form ULIS and cooled photon detector from Sofradir. The image processing module was implemented in FPGA structure and worked with external ARM processor for control and coprocessing. The paper describes the design of the processing unit, results of image processing, and parameters of module like power consumption and hardware utilization.

7660-142, Poster Session

The use of dry gas purging to prevent humidity and condensation damage of IR systems

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This paper discusses the benefits of dry gas purging and the identification of in built moisture (hygroscopic loading) within instruments and systems in order to prevent humidity and condensation damage, even equipment failures. In-built moisture has to be effectively removed during the build process. Historically, hygroscopic loading has been difficult to identify and quantify within instruments and equipments. Instruments and equipments which can be adversely affected by moisture and high humidity are: electronics, optical systems, lasers, thermal imagers, and waveguides. Water in the form of condensation or high humidity can have a harmful deleterious effect on the reliable and efficient operation of instruments and systems. The moisture contained within the airspace of an instrument or equipment can be readily and effectively removed by purging with dry gas or dry air. A hygroscopic material is one which attracts moisture from the atmosphere. A major source of moisture within instruments and equipments is held by the hygroscopic materials used in the constructional components. These components can be identified as non metallic, constructional components including circuit boards, potting compounds, wiring looms, rubbers and electronic components. Coatings including paint, impregnation and some forms of electroplating can also be considered as sources of hygroscopic moisture. The data derived from gas dry purging can be used to predict long system reliability and performance.

7660-143, Poster Session

Backscattering measurements on urban building materials using a quantum cascade laser

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Quantum cascade laser (QCL) technology continues to develop in terms of high output power, room temperature operation, broadband emission, and terahertz range. - So do applications in mid-infrared spectroscopy, such as applications in medicine and life sciences, law enforcement and homeland security and urban and industrial emission measurements. Open-path measurement system provides ground level chemical and biological weapons detection for wide area of hundreds of meters, thus it is suitable to use in urban environment and a open-path backscattering QCL system deployment may be necessary in some conditions, e.g.: barns, fields, bridges, chimneystack, intersection. While the backscatter range is low, investigation into surface albedo of buildings in the mid-infrared region is needed. We present the backscattering measurements of an urban conglomeration (brick, glass, metal, steel, aluminum, and concrete) using distributed feedback QCL operating at 5.3um and 9.6um. Real Surface roughness and irregularities in the materials are taken into account, in which, diffuse scattering refers to the signals scattered in other than the specular or lambertian direction as a result of deviations. Finally, a model is proposed to measure the overall percentage of reflectivity from a diffuse surface at different incident angles based on the backscattered signal captured by the detector.

7660-144, Poster Session

Performance enhancement of μ-bolometer by increasing fill factor

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The performance enhancing method by maximizing optical fill factor of a μ-bolometer for a given process will be discussed in this paper. The optical fill factor is one of the most important factors in the uncooled μ-bolometer performance in that responsivity is directly proportional to fill factor. Specifically, the optical fill factor is critical as the pixel pitch reduces to realize high density uncooled FPA of below 30 pitch. However, an optical fill factor is very limited for a given process, this because of the complex roles of legs in an uncooled μ-bolometer, these are thermal isolation, electrical leads, and mechanical supports of a bolometer pixel.

In this paper, a new plausible method of increasing fill factor will be proposed. The electro-optical and thermal analysis results of a proposed μ-bolometer will be also discussed. From the analysis, more than 10 % increasing of fill factor can be achieved with the proposed μ-bolometer.

A new method of increasing fill factor could be easily incorporated with a conventional process for an uncooled μ-bolometer without considerable change of process.

7660-145, Poster Session

Planar and sandwich uncooled microbolometers with $Ge_{(x)}Si_{(1-x)}x>0.5$ thermo-sensing layer deposited by plasma

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Un-cooled micro-bolometers with silicon (Si:H) thermo-sensing films in planar configurations have been reported and these devices are commercially available.

Earlier we have reported on Ge(x)Si(1-x):H x>0.5 films for thermo-sensing layers. These films are attractive because of sufficiently high conductivity activation energy and, consequently high temperature coefficient of resistance (TCR) and lower than in Si:H resistivity that reduces device resistance without doping. Here we present a study of fabrication and performance characteristics of both planar and sandwich configurations of un-cooled micro-bolometers. In order to achieve low thermo-conductance the devices were fabricated in the form of two-leg micro-bridge with surface micro machining technique. The support layer was made of silicon-nitride deposited by low frequency plasma. Thermo-sensing layer was deposited also by plasma on the top of the micro-bridge.

Metal electrodes were either planar providing current flow along thermo-sensing layer or sandwich with current perpendicular to the thermo-sensing film surface. Finally the device structure was coated by silicon-nitride film that protected the device and improved IR absorption by factor of 2. Device cell dimensions were 30x30, 40x60 (mostly used) and 100x100μm2. Current-voltage characteristics with and without IR illumination were measured and optimized bias current was determined. Responsibility of the devices was calculated from these measurements. Effective thermo-conductance and response time were measured and effective thermo-capacitance was calculated from these measurements. Noise spectra of the devices were studied in the range of frequency from 1 to 10^5 Hz that allowed determining detectivity of the devices. These data are analyzed for different micro-bolometer configurations and are compared with published data.

7660-146, Poster Session

Development of infrared detector with slot antenna-coupled microbolometer

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The current state-of-the-art infrared detection technology requires either exotic materials or cryogenic conditions to perform its duty. Implementing infrared detection by coupling infrared tuned antenna with a microbolometer offers a promising technological platform for

mass production of uncooled infrared detectors and imaging arrays. We report on the design, fabrication, and characterization of a planar slotted antenna on a thin Silicon Dioxide (SiO2) membrane for infrared detection. The planar slotted antenna was chosen due to its ease of fabrication and greater fabrication tolerance, higher gain and greater bandwidth coveted for the infrared applications. The employment of the SiO2 membrane technology mitigates the losses due to surface waves generated as the radiation coupling into the substrates. In addition, by retaining the membrane thickness to be less than a wavelength, the amount of interference is greatly reduced. A strategically designed planar slotted dipole antenna is implemented along with an integrated DC block enabled by co-fabricated on-chip capacitors between the two DC patches to separate DC and RF signals without the need for sub-micron DC separation line. As a result of this revision, standard photolithography instead of e-beam lithography can be used to fabricate the infrared detectors for mass production. On going research on characterization THz slot antenna designs and microbolometer materials including Vanadium Oxide will be reported in full paper. This research is considered as an important step toward our main goal, which is developing unltrafast infrared detector by coupling a planar slotted antenna with a MIM tunneling diode.

7660-147, Poster Session

Uncooled infrared development for small unmanned aerial vehicles

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The US Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) is developing a micro-uncooled infrared (IR) capability for small unmanned aerial systems (SUAS). Beginning in 2006, modeling and simulation activities yielded a robust sensor system design that addresses both current and future requirements for SUAS applications. In 2007, AMRDEC procured several uncooled microbolometers for lab and field test evaluations, and static tower tests involving specific target sets confirmed initial modeling and simulation predictions. With these promising results, AMRDEC procured two captive flight test (CFT) vehicles and, in 2008, completed numerous captive flights to capture imagery with the micro-uncooled infrared sensors. Several test configurations were used to build a comprehensive data set. These configurations included variations in look-down angles, fields of view (FOV), environments, altitudes, and target scenarios. Data collected during these field tests is also being used to develop human tracking algorithms and image stabilization software by the other AMRDEC personnel. Details of these ongoing efforts will be presented in this paper and will include: 1) onboard digital data recording capabilities; 2) analog data links for visual verification of imagery; 3) sensor packaging and design; which include both infrared and visible cameras; 4) field test and data collection results; 5) future plans; 6) potential applications. Finally, AMRDEC has recently acquired a 17 µm pitch detector array. The paper will include plans to test both 17 µm and 25 µm microbolometer technologies simultaneously in a side-by-side captive flight comparison.

7660-155, Poster Session

Optical design of a broadband (3-12 µm) athermal infrared imager

A. Uçar, TÜBITAK SAGE (Turkey); M. Kabak, Ankara Univ. (Turkey)

Described optical design of an imager works in two sub bands of infrared spectrum which are called midwave and longwave (3-5 ve 8-12 µm). The relevant design issue is not affected by the rate of change of temperature in terms of various season and atmosphere conditions in operation. In this study, the first attempt dealt with is to describe the broadband concept and to highlight that term. Then, the basic information is presented about infrared sub-bands. After describing the details of optical design in an infrared band, the decisions on necessary design parameters are made. In this scene, environmental conditions regarded during the design process are chosen as challenging weather conditions of TURKEY within the range 0 to 40ºC.

7660-156, Poster Session

Comparison of midwave and longwave infrared detectors used in aerial applications

A. Uçar, B. Özkan, F. Büke, TÜBITAK SAGE (Turkey)

Considering the aerial surveillance and reconnaissance applications, the use of infrared detectors gains importance. In this scene, one of the primary issues that should be decided happens to be the operating range of the detectors. Namely, the midwave and longwave ranges which are usually defined in the ranges of 3-5 m and 8-12 m, respectively, come into the picture as viable alternatives. In this work, the basic properties of infrared detectors operating in midwave and longwave regions are presented and then they are compared in terms of certain performance criteria. The study is concluded by a general evaluation.

7660-157, Poster Session

Comparison of four midwave (3-5 µm) F2 objectives in the sense of their thermal performance

A. Uçar, S. Sendogdu Yilmaz, K. D. Kandemir, TÜBITAK SAGE (Turkey)

Passive athermalization of infrared imager objectives is a critical issue which is exposed to variable atmospheric conditions like thermal goggles and binoculars. In this study, four 50 mm f2 midwave objectives three of which are commerical and rest one of which is self-designed are tretaed in the sense of modulation transfer function in Nyquist frequency under temperature range from the room temparature, i.e. 21°C, to 50°C. The test setup constructed to get the mention results and test process are explained within the scope of the present work. Finally, the attained results are comparatively evaluated.

7660-149, Poster Session

Cryogenic Fourier transform spectrometer for infrared spectral calibrations from 4 to 20 micrometers

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We present initial performance data from a cryogenic Fourier transform spectrometer (Cryo-FTS) designed for low-background spectral infrared calibrations. The Cryo-FTS operates at a temperature of approximately 15 K and has been integrated into an infrared transfer radiometer containing a calibrated Si:As blocked impurity band (BIB) detector. Due to its low operating temperature, the spectrometer exhibits negligible thermal background signal and low drift. Data from tests of basic spectrometer function, such as modulation efficiency, scan jitter, spectral range, spectral resolution and sweep speed will be presented. We will also discuss calibration techniques and results pertinent to operation of the Cryo-FTS as part of a calibration instrument, including background, signal offset and gain, and spectral noise equivalent power. The spectrometer is presently limited to wavelengths below 25 micrometers but can be in principle extended to longer wavelengths by replacing its

KBr beamsplitter with another beamsplitter engineered for use beyond 25 micrometers.

7660-153, Poster Session

Practical applications of Zernike phase surfaces in optical system modeling

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There are times when it would be helpful to share performance information about an optical system without disclosing proprietary information between multiple parties. A combination of Zernike phase surfaces and paraxial surfaces can be used to model an optical system and provide a method to safely transfer the required information without disclosing the specifics of the design such as details about the optical materials or the specific element geometry. This paper deals with some of the practical aspects of this approach such as aperture stop location, the affects of windows which may change thickness on the construction of the model, and the need for multiple field positions and wavelengths.

7660-106, Session 17

The QWIP focal plane assembly for NASA's Landsat Data Continuity Mission

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The Thermal Infrared Sensor (TIRS) is a QWIP based instrument intended to supplement the Operational Land Imager (OLI) for the NASA-USGS Landsat Data Continuity Mission (LDCM). The TIRS instrument is a dual channel far infrared imager with the two bands centered at 10.8μm and 12.0μm. The focal plane assembly (FPA) consists of three 640x512 GaAs Quantum Well Infrared Photodetector (QWIP) arrays precisely mounted to a silicon carrier substrate that is mounted on an invar baseplate. The two spectral bands are defined by bandpass filters mounted in close proximity to the detector surfaces. The focal plane operating temperature is 43K. The QWIP arrays are hybridized to Indigo ISC9803 readout integrated circuits (ROICs). Two varieties of QWIP detector arrays are being developed for this project, a corrugated surface structure QWIP and a grating surface structure QWIP. This paper will describe the TIRS performance requirement (NEdT) as it relates to the QWIP focal plane performance requirements: spectral response, dark current, conversion efficiency, read noise, temperature stability, pixel uniformity and pixel yield. Additional mechanical constraints as well as thermal cycling and vibration qualification through Technology Readiness Level 6 (TRL 6) will also be discussed.

7660-107, Session 17

C-QWIPs for far-infrared detection

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We have extended our investigation of C-QWIP FPAs into the far infrared regime. Specifically, we are developing the detectors for the Thermal Infrared Sensor used in the Landsat Data Continuity Mission. This mission requires infrared detection up to 13 microns and the FPAs operated at 43 Kelvins. To maintain a low dark current in these extended

wavelengths, we adopted a low doping density of 0.6E18 cm-3 and a bound-to-bound detector. The internal absorption QE is calculated to be 23.2% for a pixel pitch of 25 microns and 60 periods of QWs. With a pixel fill factor of 80% and a substrate transmission loss of 29.1%, the external QE is 13.2%. To project the conversion efficiency, we measured the photoelectron transmission coefficient of this B-B detector and the photoconductive gain. From this experiment, CE is predicted to be 2.1%. This value is in agreement with the measured 2.05% from several FPAs. Meanwhile, the pixel dark current is measured to be 1.1E-8 e/s around 43 K, and it is about 45 times less than the photocurrent with F/2 optics. The corresponding detector limited NETD is 16 mK at 2 ms integration time in the presence of 900 read noise electrons, and it increases to 20 mK at 50 Kelvins. The highest operability is 99.967%. With the CE agreement, we performed a systematic analysis on the FPA performance in the far infrared regime up to 30 microns. Their NETD as a function of operating temperature and system noise will be presented.

7660-108, Session 17

Demonstration of megapixel dual-band QWIP focal plane array

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In this presentation we report the first demonstration of the megapixel-simultaneously-readable and pixel-co-registered dual-band QWIP focal plane array (FPA). The dual-band QWIP device was developed by stacking two multi-quantum-well stacks tuned to absorb two different infrared wavelengths. The full width at half maximum (FWHM) of the mid-wave infrared (MWIR) band extends from 4.4 - 5.1 μm and FWHM of the long-wave infrared (LWIR) band extends from 7.8 - 8.8 μm. Dual-band QWIP detector arrays were hybridized with direct injection 30 μm pixel pitch megapixel dual-band simultaneously readable CMOS read out integrated circuits using the indium bump hybridization technique. The preliminary data taken from the first megapixel QWIP FPA has shown system NEΔT of 27 and 40 mK for MWIR and LWIR bands respectively.

7660-109, Session 17

QWIP responsivity prediction using the transfer matrix method

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This paper presents a method to predict the responsivity of quantum well infrared photodetectors based in interband and intersubband transitions. The transfer matrix method (TMM) is used in a self consistent loop to calculate initial and final states as well as their respective wavefunctions, allowing the estimation of the absorption coefficient along the entire detection range. The transmission coefficient (tunneling factor) is also computed using the TMM. The spectral response is compared with measurements of AlGaAs/GaAs/InGaAs QWIPs sensitive to NIR, MWIR and LWIR, showing a good match. The results indicate that the technique has a great potential to be used in QWIP design.

7660-110, Session 17

Uncooled SWIR InGaAs/GaAsSb type-II quantum well focal plane array

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Low dark current photodiodes (PDs) in the short wavelength infrared (SWIR) at 2.5μm region, are expected for many applications such as environmental gas detection, process check in chemical plants, and

biodiagnostics. HgCdTe (MCT) is predominantly used for infrared imaging applications. However, because of high dark current, MCT device requires a refrigerator which increases power consumption, size and cost of the system. Recently, InGaAs/GaAsSb type II quantum well structures were considered as attractive material system for realizing low dark current PDs owing to lattice-matching to InP substrate.

Planar type pin-PDs were successfully fabricated.The absorption layer with 250 pair-InGaAs(5nm)/GaAsSb(5nm) quantum well structures was grown on S-doped (100) InP substrates by solid source molecular beam epitaxy method. InP and InGaAs were used for cap layer and buffer layer, respectively. The p-n junctions were formed in the absorption layer by the selective diffusion of zinc. SiN and SiON were used for passivation and anti-reflection, respectively. Low dark current was obtained by improving GaAsSb crystalline quality. Dark current density was 0.92mA/cm2 which was smaller than that of a conventional MCT.

Based on the same process, a 320x256 planar type focal plane array was also fabricated. Each photodiodes has 15μm diameter and 30μm pitch and it was bonded to read-out IC by using indium bump flip chip process. Finally, we have successfully demonstrated the 320 x256 SWIR image at room temperature. This result means that planer type photodiode array with the type II InGaAs/GaAsSb quantum well structure is a promising candidate for uncooled applications.

7660-111, Session 17

Design and characterization of strain-compensated InGaAs/GaAsSb type-II MQW structure with operation wavelength at ~3 μm

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InGaAs/GaAsSb type-II multiple quantum wells (MQWs) grown on InP substrates by metalorganic chemical vapor deposition (MOCVD) were investigated for potential operation wavelengths in the mid-infrared spectral region. Electrons and holes are spatially separated and located in the InGaAs conduction band and GaAsSb valence band, respectively. The resulting spatially indirect type-II emission occurs at longer wavelength than the spatially direct intraband recombination in either InGaAs or GaAsSb. A 4-band k p Hamiltonian model was employed to calculate emission wavelengths and wavefunction overlaps. The conduction and valence band material parameters used for the calculations are taken from the review and experimental literatures. [1,2] In order to grow thick and high quality MQWs and ease the difficulty of MOCVD growth of GaAsSb, the Sb concentration is modified slightly around 0.49. A pin structure with 100 pairs of In0.45Ga0.55As (~7.0 nm)/GaAs0.40Sb0.60 (~5.0 nm) MQWs structure with operation wavelength of ~3 um was designed and grown by MOCVD. The compressively strained GaAsSb layers are strain-compensated by the tensively strained InGaAs layers and the total strain in the MQW is ~ zero. I-V measurements at room and low temperatures and quantum efficiency (QE) measurement are in progress.

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7660-113, Session 17

Integration of multispectral infrared quantum dots-in-a-well photodetectors into focal plane arrays

J. A. Montoya, R. V. Shenoi, Y. Sharma, J. Shao, A. V. Barve, H. Kim, S. Krishna, Ctr. for High Technology Materials (United States)

Next generation infrared photodetector technology will require focal plane array (FPA) systems that have multi-spectral imaging capabilities. Use of plasmonic photonic crystals to selectively manipulate the incoming electromagnetic radiation for this goal is proposed. However, it was found that inconsistent characterization measurements occur for devices with a varying optical aperture area. It is proposed that the substrate scattering effect, which is electromagnetic radiation that enters the active of a photodiode as a result of radiation scattered from the substrate, is the cause of this inconsistency. In addition, the quality factor of devices integrated with a plasmonic crystal cavity could be limited as a result of substrate scattering. Here, we propose a scheme for accurate measurement of device performance by using a fanout chip design that is similar to the fabrication of an FPA system, with the substrate removed through a combination of mechanical polishing and subsequent wet etching techniques. The fanout chip was also designed to precisely characterize the effects of varying mesa size by incorporating square mesa structures that range from 250 to 25 microns in width. This approach offers an advantage over conventional device characterization (typically a 410 x 410 micron mesa) because it incorporates mesas that are on the same scale as those normally used in FPA systems, which should therefore provide a fast transition of new photodetector technology into camera based systems. The photodetector technology chosen for this work is a multi-stack quantum dots-in-a-well (DWELL) structure designed to absorb electromagnetic radiation in the mid-infrared spectral range.

7660-114, Session 17

State of the art of quantum cascade photodetectors

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The Quantum Cascade Detector (QCD) is a multiple quantum well photodetector working at low bias or zero bias. It has a zero dark current occurring at 0V, together with a high photovoltaic photoresponse, since the QCD does not need any applied field to improve the collection of electrons. QCDs have been tested at various wavelengths, from short wavelengths (1.5 microns) up to THz waves, through the entire infrared spectrum (middle and long wavelengths). Theory of transport in QCD is now well established, and leads to accurate calculations of current and noise in QCDs, with a very good agreement with experimental results. Latest results and state of the art of performances of QCDs will be presented.

7660-116, Session 18

"On chip" Fourier processing to enhance SNR in the presence of noise

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Over the last three years Lockheed Martin's Advanced Technology Center in Palo Alto has developed a prototype 8x8 NIR focal plane capable of simultaneous Fourier processing per pixel. Experiments will be described in which 10 khz Fourier processed frame rates are used to drive a closed loop tracking servo loop. The pointing direction of one laser with wavelength 1, and amplitude modulation f1 is adjusted with a fast stirring mirror to track the motion of two targets illuminated by two other lasers with wavelengths 2 and 3, amplitude modulated at two other distinct frequencies. Closed loop tracking control at 1khz is demonstrated using only the single 8x8 focal plane to sense position of the three lasers simultaneously at all pixels. Random noise generated by heat sources and a fan applied to the track laser beam path, and a white light source with 1000x larger signal then the received laser signal shown directly on the focal plane, has no effect on the track loop.

A final discussion and series of experiments will show the capability of the sensor to simultaneously measure range, as well as position.

7660-117, Session 18

A 25 µm pitch LWIR focal plane array with pixel-level 15b ADC providing high well capacity and targeting 2 mK NETD

F. Guellec, A. Peizerat, M. Tchagaspanian, E. De Borniol, S. Bisotto, P. Castelein, J. Zanatta, Commissariat à l'Énergie Atomique (France)

CEA Leti has recently developed a new readout IC (ROIC) with pixel-level ADC for cooled infrared focal plane arrays (FPAs). It operates at 50Hz frame rate in a snapshot Integrate-While-Read (IWR) mode. It targets applications that provide a large amount of integrated charge thanks to a long integration time. The pixel-level analog-to-digital conversion is based on charge packets counting. This technique offers a large well capacity that paves the way for a breakthrough in NETD performances. The 15 bits ADC resolution preserves the excellent detector SNR at full well (3Ge-). These characteristics are essential for LWIR FPAs as broad intra-scene dynamic range imaging requires high sensitivity. The ROIC, featuring a 320x256 array with 25µm pixel pitch, has been designed in a standard 0.18µm CMOS technology. The main design challenges for this digital pixel array (SNR, power consumption and layout density) are discussed. The IC has been hybridized to a LWIR detector fabricated using our in-house HgCdTe process. The first electro-optical test results of the detector dewar assembly are presented. They validate both the pixel-level ADC concept and its circuit implementation. Finally, the benefit of this LWIR FPA in terms of NETD performance is demonstrated.

7660-118, Session 18

Improved MWIR reference sources for FPA non-uniformity correction

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We have previously discussed the potential of using an MCT source as a reference plane for the non-uniformity correction of thermal imagers. Due to the fast switching speed, the apparent temperature can be changed on a frame to frame basis. This allows multipoint correction data to be obtained without having to wait for temperatures to stabilize as with a Peltier reference source. Also, the operation of the device can be synchronized to the integration period of the camera to reduce the mean power requirements by a factor of 10 and reduce thermal heating effects.

In this paper we discuss a practical implementation of this concept in a thermal imaging camera, which is being developed as part of the UK MOD Albion program. This development has involved increasing the device size, increasing the effective temperature range and matching the drive requirements to typical camera power supplies. The factors determining the achievable effective temperatures will be discussed, together with modifications to the structure that have been implemented to obtain a useful temperature range. The drive requirements have been improved by developing a series connected structure. This has reduced the peak current by a factor of 4 and allows the devices to be controlled with conventional Peltier reference electronics rather than a custom unit. The improved devices have now been incorporated into a state-of-the-art infrared camera and their performance in this system will be discussed.

7660-120, Session 18

Scaling and application of commercial feature-rich modular mixed-signal technology platform for large format ROICs

A. Kar-Roy, M. Racanelli, D. Howard, G. S. Miyagi, M. Bowler, S. Jordan, T. Zhang, W. Krieger, Jazz Semiconductor (United States)

Modular mixed-signal platform is applied to highly integrated, large-format ROIC manufacturing. The availability of 4fF/um2 stacked MIM capacitors and 1kohm/sq high-value poly resistors in the commercial CA18HD dual gate 1.8V/3.3V 0.18um RF/mixed signal process allows improved sensitivity capacitive transimpedance amplifiers (CTIA) designs and on pixel analog-to-digital converters. Reduced I-R drop and efficient power distribution is achieved by using the 3um thick top metal available in this process. Features of silicon accurate cryo models and room temperature scalable, statistical and corner models, which mitigate design sensitivity to process variations and enables first pass design success for ROIC designs for both cooled and uncooled FPAs, will be described. Use of the commercial CA18HA process with similar mixed signal components as the CA18HD process but with dual gate 1.8V/5V FETs, 40V LDMOS FETs, and a combination of high performance NPNs and PNPs enables next generation ROIC designs for uncooled FPAs. Key characteristics of these modular devices for ROIC applications, along with higher capacitance per unit area and local processing within the input cells with higher transistor density per unit area while preserving analog-friendly 3.3 and 5V trasistors, will be presented. These platforms are being considered for next generation large format ROICs. Stitching option is available for these processes. We will describe several aspects of design for manufacturing tools for large die designs and improved die yields.

7660-121, Session 19

Optimizing size, weight, and power in 17 µm pitch LWIR cameras

T. R. Beystrum, L-3 Communications Infrared Products (United States)

The success uncooled thermal imaging systems in soldier borne (man-wearable or weapon-mounted) and micro/mini UAV applications continues to depend on the total system size, weight and power even as focal plane array (FPA) pitch migrates to 17µm. Unique FPA packaging facilitates reduced size and weight. The allocation of signal and video processing between readout integrated circuits (ROICs), field programmable gate arrays (FPGAs) and other processors also drives the success of the system design. Both multi-use and purpose-built electronics approaches will be considered as paths to elegant system designs based on amorphous silicon uncooled microbolometer FPAs.

7660-123, Session 19

Passive ranging using mid-wavelength infrared atmospheric attenuation

D. Macdonald, M. R. Hawks, K. C. Gross, Air Force Institute of Technology (United States)

Methods of estimating range to an emissive target based on the depth of an atmospheric absorption band are demonstrated. The present work applies techniques demonstrated with the CO_2 absorption band centered at 2.0 µm where signal-to-background ratios are higher for many applications. Model results, based on high-resolution transmission molecular absorption (HITRAN) database cross sections, are used to predict range accuracy at ranges of up to 50 km and are compared with short range (<5km) experimental results. The spectra of 23 high explosive events were used to validate the model. Using the assumption of a blackbody spectrum, extracted ranges consistently underestimated

the true range by approximately 13%. These estimates were improved by incorporating the stoichiometry of the fireball from previous research and using particulate contribution as a parameter. Not only were errors reduced to 3%, intimations suggesting that target discrimination could be achieved using the particulate parameter were also observed.

7660-124, Session 19

Analysis and quantification of laser-dazzling effects on IR focal plane arrays

N. Hueber, Institut Franco-Allemand de Recherches de Saint-Louis (France); D. Vincent, Defence Research and Development Canada (Canada); A. Dieterlen, Univ. de Haute Alsace (France); A. Morin, Defence Research and Development Canada (Canada); P. Raymond, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Today Optronic CounterMeasure (OCM) concerns imply an IR Focal-Plane Array (FPA) facing an in-band laser irradiation. In order to evaluate the efficiency of new countermeasure concepts or the robustness of FPAs, it is necessary to quantify the whole interaction effects. Even though some studies in the open literature show the vulnerability of imaging systems to laser dazzling, the diversity of analysis criteria employed does not allow the results of these studies to be correlated.

Therefore, we focus our effort on the definition of common sensor figures of merit adapted to laser OCM studies. In this paper, two investigation levels are presented: the first one for analysing the local nonlinear photocell response and the second one for quantifying the whole dazzling impact on image.

The first study gives accurate results on InSb photocell behaviors when irradiated by a picosecond MWIR laser. With an increasing peak power density, four different successive responses appear: linear, logarithmic, decreasing ones and permanent linear offset response. Moreover, we show how the decreasing response of the most irradiated pixels spreads toward the surrounding pixels of the array.

In the second study, we propose an experimental framework and image processing tools for measuring every observed phenomenon within the dazzled image. By means of local statistical information from pixel luminance, we have defined four criteria so as to quantify the contour and contrast loss, the noise and saturation variations. This paper describes these tools and demonstrates their successful implementation through the picosecond laser-dazzling characterization of an InSb FPA.

7661-01, Session 1

The use of infrared imagery to quantify near-surface thermal and hydrodynamic features on bodies of water

K. P. Judd, R. Handler, U.S. Naval Research Lab. (United States)

Infrared imaging has proven to be an invaluable tool for remotely detecting and tracking coupled near-surface thermal-hydrodynamic structures such as foam patches of breaking waves, Langmuir circulation and convective cells, thermal impressions of water mass movement and pollutant effluxes. The ability to quantify such characteristics is vital to determining the complex nature of heat transport, gas entrainment and momentum exchange across air-water interfaces. These physical processes play an important role in determining global climate and their accurate description is necessary for consistent weather modeling. In this presentation, we focus on a laboratory scale subsurface turbulent water jet that serves as a canonical near surface event. The jet liquid has a slightly elevated temperature and is placed in close proximity to the air-water interface of a quiescent water basin into which it flows. Infrared image sequences of the surface thermal field were collected for various water jet flow rates and used to examine the detailed statistical nature of the resulting coupled thermal-hydrodynamic field. We discuss the similarities of the spatial structure of the surface thermal field in light of observations made with other sensing techniques, the relevant length and thermal scales present and the order of the fluctuating surface thermal field using Karhunen-Loeve analysis.

7661-02, Session 1

Thermodynamics of partially frozen cooling lakes

A. J. Garrett, Savannah River National Lab. (United States)

The Savannah River National Laboratory (SRNL) and the Rochester Institute of Technology (RIT) are investigating the behavior of a cold climate power plant cooling lake that is subject to extensive freezing during the winter months. The objective of this research is to determine if remote sensing data can be used to understand how formation of ice over the colder parts of the lake affect circulation, heat transfer and temperature structure in the lake. SRNL is modeling the fluid dynamics, heat transfer and ice formation on the lake using a combined hydrodynamic - ice physics code. Part of the numerical simulation analysis is directed at understanding the effects of an insulating layer of snow on top of the ice. RIT is collecting both ground truth (ice and water temperature, weather data, solar and thermal radiation fluxes) and airborne imager data to provide validation data for the simulations. RIT is using a multispectral imager (visible, SWIR, MWIR, LWIR) to image the cooling lake from a small aircraft. RIT also developed a ground-based system to collect images that are used to calculate the amounts of the lake that are ice-free and ice-covered. Initial results show that the coupled hydrodynamic - ice model simulations have significant skill at reproducing the measured ice formation rates and ice distribution over the lake. Sensitivity runs show that ice thickness and distribution are somewhat sensitive to the presence of snow on the ice. The simulations also show that the presence of warm water under the ice makes it much more sensitive to variables such as wind speed and direction.

7661-03, Session 1

Improved temperature retrieval methods for the validation of a hydrodynamic simulation of a partially frozen power plant cooling lake

M. V. Casterline, C. Salvaggio, Rochester Institute of Technology (United States); A. J. Garrett, Savannah River National Lab. (United States); J. W. Faulring, B. D. Bartlett, P. S. Salvaggio, Rochester Institute of Technology (United States)

The ALGE code is a hydrodynamic model developed by Savannah River National Laboratory (SRNL) to derive the power output levels of a power generation site from observing the site's associated cooling pond with an aerial imaging platform. Over the past two years work has been completed to extend the capabilities of the model to be able to incorporate snow and ice as possible phenomena in the modeled environment. In order to validate the extension of the model, intensive ground truth data collections as well as high-resolution aerial infrared imagery collections were completed over two winters, for a combined eight months of data collection. Due to the harsh and extreme environment automatic data collection instruments were designed and deployed. Based on previous winters' experiments and equipment design failures, massive overhauls in the design and operation of automated data collection buoys were performed. In addition, a more thorough and robust two-fold calibration technique was implemented within the aerial imaging chain to produce precise accuracy values for retrieved temperatures. By design, the calibration method employed in this application uses ground collected, geo-located water surface temperatures and in-flight blackbody imaging to produce accurate temperature maps of the pond in interest. A sensitivity analysis was implemented within the processing technique to produce accurate sensor reaching temperature values as well as a re-design in the equipment and methods for temperature retrieval at the water's surface.

7661-04, Session 1

Wind-influence modeling for outdoor thermographic surveys

E. C. Bortoni, Univ. Federal de Itajubá (Brazil)

Thermography is widely applied to power systems in the power substations and in the overhead transmission lines condition monitoring, aiming at continuous operation and maintenance purposes. As applied in an outdoor environment, the themographyc inspection is influenced by a number of ambient conditions such as wind, solar radiation, humidity, and so forth. A great challenge for the researchers consists in the development of methods to extract the influence of such ambient variables in order to get the most reliable diagnostic.

Therefore, a novel model to determine the wind influence from themographic inspections is addressed in this paper. A wind velocity dependent temperature reduction factor is developed and applied in order to estimate the target temperature in the absence of wind. The model makes use of only two unknown coefficients which are identified for each case.

Tests were conducted in laboratory using an aclimatiezed chamber developed to simulate actual conditions, and in the field. The results of the modeling application were also compared to that obtained from other researchers, showing very good agreement and proving to be flexible enough to be widely applied. Discussion on the wind influence in comparison with the heat origin location will also be addressed.

7661-05, Session 1

IR thermography as an instrument for investigations of an influence of thin coatings layers on liquid-metal cooling of steel wall

J. A. Patorski, R. Milenkovic, Paul Scherrer Institut (Switzerland)

After excellent results of MEGAPIE neutron-spallation-source, the Paul Scherrer Institute PSI has started the project named LIMETS (Liquid-Metal-Target-for-SINQ) with goal to develop a permanent standard Liquid-Metal (LM) Lead Bismuth Eutectic (LBE) target. At the beginning of LIMETS design, we have to clarify some proton beam entry window cooling questions connecting with: longer life-time of exploitation (2 years), higher velocity of LM coolant (1 m/s) and stronger current of proton beam (3 mA).

Only the protection against LM corrosion-&-erosion in higher temperatures becomes more important and can be done by a special treatment of the window's wall.

From one hand a covering with merely few micrometers layer of special materials (e.g. Titanium-Nitride or oxides of window's material as T91-steel) can avoid corrosion-erosion problems caused by irradiation, high LM-LBE velocity and temperature.

From second hand such thin layer can essentially change the whole thermal resistance of the window wall because high thermal contact resistance and finally the window's cooling i.e. heat transfer coefficient (HTC) can be negative influenced.

The characteristic physical phenomena governing this possible change of HTC can be wetting, therefore we have started the experimental investigation named COOLWETT. The influence of different treatment of steel window surfaces, building thin layers contacting LBE, on HTC will be tested. For the determination of HTC the methodology using Infrared Thermography, as it was published during Thermosense in 2006 will be used.

The goals, set up of the test section, instrumentation and the actual results of the COOLWETT experiment series will be presented during the Thermosense-XXXII.

7661-06, Session 2

Infrared face recognition using texture descriptors

M. A. Akhloufi, A. H. Bendada, Univ. Laval (Canada)

Face recognition is an area of computer vision that has attracted a lot of interest from the research community. A growing demand for robust face recognition software in security applications has driven the development of interesting approaches in this field. A large quantity of research in face recognition deals with visible face images. In the visible spectrum the illumination and face expressions changes represent a significant challenge for the recognition system. To avoid these problems, researchers proposed recently the use of 3D and infrared imaging for face recognition.

In this work, we introduce a new framework for infrared face recognition using texture descriptors. This framework exploits non linear dimensionality reduction techniques, developed recently, for face learning and recognition in the texture space. Active and passive infrared imaging modalities are used and comparison with visible face recognition is performed. Two multispectral face recognition databases were used in our experiments: Equinox Database (Visible, SWIR, MWIR, LWIR) and Laval University Multispectral Database (Visible, NIR, MWIR, LWIR).

The obtained results show high increase in recognition performance when texture descriptors like LBP (Local Binary Pattern) and LTP (Local Ternary Pattern) are used, particularly in the short wave infrared spectrum (SWIR) using non linear dimensionality reduction techniques.

7661-08, Session 2

The application of advanced image processing to rescue camera systems

D. L. Hickman, T. Riley, L. Swan, Waterfall Solutions Ltd. (United Kingdom); C. Humpoletz, ISG Thermal Systems Ltd. (United Kingdom)

Hand-held thermal imaging systems are an important search tool for fire services and rescue services. However, in order to achieve wide-spread deployment, the cost of such systems must be minimised and this generally leads to reduced image quality. Within this paper, the use of advanced image processing functions to increase the imaging system performance is discussed. Of particular note is the use and benefits of noise reduction, contrast enhancement, and super-resolution techniques. Results from a developed camera system are presented and the performance gains are illustrated.

7661-09, Session 2

Multimodal panoramic imaging for security and surveillance applications

M. Bernhardt, J. R. E. Sadler, D. L. Hickman, J. Davis, T. Riley, Waterfall Solutions Ltd. (United Kingdom); A. Thomas, C. Dent, BAE Systems (United Kingdom)

The Panoramic Area Surveillance System (PASS) provides a unique imaging and processing capability for a wide range of security and situational awareness applications. PASS comprises a network of multi-modal cameras and its operational performance is derived from a range of extensive image and data processing functions implemented as real-time software on commercially available hardware. The development of PASS has offered a number of design challenges, including the balance between implementation constraints and system performance. Within this paper, the PASS system and its development challenges are described and its operation is illustrated through a range of application examples.

7661-10, Session 3

Development of a nondestructive evaluation method for FRP bridge decks

J. R. Brown, T. Fox, Hope College (United States)

Open steel grids are typically used on bridges to minimize the weight of the bridge deck and wearing surface. These grids, however, require frequent maintenance and exhibit other durability concerns related to fatigue cracking and corrosion. Bridge decks constructed from composite materials, such as a Fiber-reinforced Polymer (FRP), are strong and lightweight; they also offer improved rideability, reduced noise levels, less maintenance, and are relatively easy to install compared to steel grids. This research is aimed at developing an inspection protocol for FRP bridge decks using thermal imaging. The finite element method was used to simulate the heat transfer process and determine optimal heating and data acquisition parameters that will be used to inspect FRP bridge decks in the field. It was demonstrated that thermal imaging could successfully identify features of the FRP bridge deck to depths of 1.7 cm using a phase analysis process.

7661-11, Session 3

Accuracy improvement of self-reference lock-in thermography method and its application to detection of fatigue crack in steel bridges

Y. Izumi, Osaka Univ. (Japan); T. Sakagami, Kobe Univ. (Japan); S. Kubo, Osaka Univ. (Japan)

A new remote nondestructive inspection technique, based on thermoelastic temperature measurement by infrared thermography was developed for evaluation of fatigue cracks propagated from welded joints in steel bridges. Fatigue cracks were detected from localized high thermoelastic temperature change observed at crack tips due to stress singularity under variable loading by traffics on the bridge. Self-reference lock-in data processing technique was developed for improvement of signal/noise ratio of the thermal images in the crack detection process. In this paper, remote and nondestructive crack detections by the self-reference lock-in thermography were performed for fatigue cracks in actual steel bridge in service. Accuracy improvement of self-reference lock-in thermography method was made by motion compensation technique.

7661-12, Session 3

Determination of delamination depth in concrete structure based on inverse analysis of thermography data

T. Cheng, Osaka Univ. (Japan); T. Sakagami, Kobe Univ. (Japan); S. Kubo, Osaka Univ. (Japan)

Passive infrared thermography is an effective technique for detecting delamination in concrete structures. This research investigates the possibility of quantitative determination of delamination depth using passive lock-in infrared thermography. The Fourier coefficients were calculated from transient temperature change, and the difference of the coefficients was evaluated between sound area and defect area. FEM analyses are carried out to simulate the transient thermal conduction in the concrete structure. Based on the experimental and numerical results, delamination depth was quantitatively determined based on the inverse analysis schemes.

7661-13, Session 3

Nondestructive testing of plastered mosaics with the use of active thermography approaches

E. Cheilakou, N. P. Avdelidis, National Technical Univ. of Athens (Greece); C. Ibarra-Castanedo, Univ. Laval (Canada); M. Koui, National Technical Univ. of Athens (Greece); A. H. Bendada, X. P. Maldague, Univ. Laval (Canada)

Since there are strict conservation regulations as far as mosaics and/or historical sites are concerned, the use of non destructive testing and evaluation techniques is considered to be essential. Active thermography in civil engineering can be used efficiently in a variety of applications. The mosaic beneath the plastered surface (i.e. detection of subsurface) due to the different thermal diffusivity that they present can be realized by different surface temperature. In this work, different mosaics covered with various plasters (of thickness and compositions) were evaluated in lab by means of active long wave, mid wave and near infrared thermography approaches, with the intention of detecting the tesserae beneath the plastered surface. Thermal images as well as thermal contrast curves between plastered surfaces and plastered mosaics were recorded. Special considerations concerning the applicability and accuracy of the used approaches for this specific application are presented. Results from

the assessment are presented and discussed, indicating that images seeing through the mortar-plaster on plastered mosaic surfaces can be obtained using active thermography approaches. From the results obtained it is concluded that thermography should be considered as a valuable appraisal non destructive tool in the investigation of plastered mosaics surfaces.

7661-14, Session 3

IR thermography applied to the assessment of thermal conductivity of building materials

P. Bison, E. G. Grinzato, Consiglio Nazionale delle Ricerche (Italy)

The standard method to measure the thermal conductivity of a solid material is based on the Fourier law. In steady state conditions the heat flux (q [W]), flowing through a slab sample, is equal to the temperature difference between the two sides of the slab, times a constant factor typical of the material, that is the thermal conductivity ([W m-1 K-1]), times the ratio between the surface of the slab S and the thickness l.

An apparatus, formed by two thermoelectric devices, sandwiching a homogeneous specimens with flat parallel faces, in the form of slabs, generate a constant 1D density of heat flux by heating the top and cooling the bottom sides of the specimen respectively. The thermoelectric devices are used as a controlled source of heat flux. That is possible once their characteristic constants are known, together with the working temperatures and the supplied electric current. The temperature gradient, across the whole specimen, is measured by IR thermography. Moreover, the lateral view of the thermoelectric devices represents well their effective states as much as the 1D heat diffusion is realized. In order to avoid the need of a surrounding guard section, tests are performed around room temperature, paying attention to limit as much as possible the heat exchanged with the environment.

Tests are carried out on several samples made of a mixture of materials especially suited for radiant floor heating system. The thermal parameters of such samples are measured with alternative methods (flash method for diffusivity, calorimeter for specific heat and Archimedes' principle for density) for comparative purpose.

7661-15, Session 3

R-value estimation by local thermographic analysis

E. G. Grinzato, Consiglio Nazionale delle Ricerche (Italy); F. Peron, Univ. Ca' Foscari di Venezia (Italy); P. Bison, Consiglio Nazionale delle Ricerche (Italy)

IR thermography is able to detect very accurately temperature difference between air and surface. The instantaneous heat flux through the inner surface of a room is monitored starting from a local mapping of such a data, with the help of the outside air temperature. In case of steady thermal state, this gives the thermal performance evaluation of the building envelope. In case of a transient condition an averaging process or a system identification algorithm must be applied on time-series of such a data. In any case, it is demonstrated that a conventional technique based on thermal flux meter for the thermal resistance (R-value) measurements is more affected by errors than thermographic measurements.

The improvements given by this paper is the evaluation of both convective and radiative heat flux on a local basis with a space resolution of 1 cm.

Tests on laboratory controlled environment and in situ are reported.

7661-16, Session 3

Detection of buried pipelines from IR images using fractal dimension analysis

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Infrared images of pipelines buried in soil were obtained in the 8-12 micrometers spectral range using a microbolometer CCD camera. The temperature of the surface of the soil depends on the heat transfer between the pipe and the surrounding soil.

The detection and identification is performed through a segmentation process of the images. In the segmentation of the images we use local fractal dimension analysis (LFD) as a feature descriptor computed in a per pixel basis. The set of features is clusterized by means of the k-means method. We use two different LFD estimators, box counting dimension, and box counting differential dimension. This segmentation technique produces outstanding results, with little computational cost.

This technique will be use to determine the location of buried pipes that transport oil, gases, or water; and it will be also useful in industrial applications such as failure detection and predictive maintenance.

We present the results of the application of this method for the detection of buried pipelines in two types of soil and discuss the advantages of its use.

7661-17, Session 4

Processing near-infrared imagery of hypersonic space shuttle reentries

T. S. Spisz, J. C. Taylor, D. M. Gibson, K. Osei-Wusu, The Johns Hopkins Univ. (United States); T. J. Horvath, J. N. Zalameda, D. M. Tomek, NASA Langley Research Ctr. (United States); A. B. Tietjen, Computer Sciences Corp. (United States); S. Tack, Naval Air Warfare Ctr. Weapons Div. (United States); R. J. Schwartz, ATK Space Systems (United States); P. Bernascolle, Bertin Technologies (France)

High-resolution, calibrated, near-infrared imagery of the Space Shuttle during reentry has been obtained by a US Navy NP-3D Orion aircraft as part of NASA's HYTHIRM (Hypersonic Thermodynamic InfraRed Measurements) project. The long-range optical sensor package is called Cast Glance. Three sets of imagery have been processed thus far: 1) STS-119 when Shuttle Discovery was at 52 km away at Mach 8.4, 2) STS-125 when Shuttle Atlantis was 71 km away at Mach 14.3, and 3) STS-128 when Shuttle Discovery was at 80 km away at Mach 14.7. The challenges presented in processing a manually-tracked high-angular rate, air-to-air image data collection include management of significant frame-to-frame motions, motion-induced blurring, changing orientations and ranges, daylight conditions, and sky backgrounds (including some cirrus clouds). This paper describes the processing of the imagery. Our goal is to reduce the detrimental effects due to motions (sensor and shuttle), vibration, and atmospherics for image quality improvement, without compromising the quantitative integrity of the data, especially local intensity variations. Our approach is to select and utilize only the highest quality images, register many co-temporal image frames to a single image frame, and then add the registered frames to improve image quality and reduce noise. These registered and averaged intensity images are converted to temperatures on the shuttle's windward surface using preflight calibration data. Comparisons with thermocouples at different points along the space shuttle and between the three reentries will be shown.

7661-18, Session 4

Recent experiments assessing the uncertainty of metal cutting temperature measurements when using the NIST high-speed dual-spectrum optical system

E. Whitenton, A. Cooke, J. Heigel, National Institute of Standards and Technology (United States); I. Arriola Aldamiz, Mondragon Univ. (Spain)

Finite element modeling simulations are an important method for optimizing the metal cutting process, allowing industry to make parts faster, better, and at less cost. Measurements of the process can be used to improve and verify the accuracy of these simulations. There are many error sources when using infrared radiation thermography to measure the temperature distribution of the tool, workpiece, and chip during metal cutting. However, metal cutting presents unique measurement challenges due to factors such as the high magnification required, high surface speeds, micro-blackbody effects, and changing emissivity as chips form.

As part of an ongoing effort to improve our understanding of uncertainties associated with these measurements, two experiments were performed. One experiment explored how well the surface temperature of the cutting tool accurately reflects the internal temperature. This was accomplished by simultaneously measuring the temperature using both a thermal camera and a thermocouple embedded within the cutting tool.

The other experiment investigated correcting for motion blur, size-of-source effects, and a less than ideal dynamic range of the thermal camera when measuring the shear zone temperature of the chip. In theory, this correction could be performed using deconvolution. Unfortunately, deconvolutions are sensitive to noise and it is difficult to gauge the uncertainty of the computed values. Thus, convolutions of various assumed inputs were computed and compared to the measured temperatures. Assumed inputs which yielded a good fit to the measured temperatures were assumed to be plausible. The range of those plausible values is a measure of the uncertainty of the calculation.

7661-19, Session 4

IR gas imaging in an industrial setting

E. Naranjo, S. B. Baliga, General Monitors Inc. (United States); P. Bernascolle, Bertin Technologies (France)

Uncooled thermal cameras using microbolometer focal plane arrays may be used in the long wave infrared (LWIR) for the optical detection of hydrocarbon gas leaks. The strong absorption of hydrocarbon gases in the LWIR may be used to advantage along with the LWIR optical transmission window of the atmosphere. Improvements in the detection algorithm and more robust electronic hardware have produced a gas imager that is well adapted to the detection of large hydrocarbon leaks. The new imaging system relies on a single set of filters to identify a growing list of gases, up to four of them simultaneously. The new detection algorithm reduces the incidence of false alarms by masking portions of the field of view. Because of the camera's long detection range (2 km) and wide field of view, the system is particularly suitable for the supervision of large industrial zones. Results from a field test of leaking gas at a refinery and natural gas processing facility are presented.

7661-20, Session 4

Unique solution for accurate in-situ infrared profiling in reheat furnaces

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As thermal imaging becomes a more accepted technology in industrial environments it can provide exciting new solutions to applications that have been previously dominated by single point pyrometers. The new development of an uncooled focal plane array thermal imager with a narrow band 3.9µm filter and background compensation processing enables measurements in industrial furnaces to provide temperature profiling of the product.

The selection of this wavelength allows the instrument to measure accurately through smoke and flames while the addition of a water-cooled, air purged borescope allows the camera to penetrate through the refractory walls of the furnace. This unique combination allows plant operators to accurately profile the temperature of the entire furnace while minimising wasted energy through the opening in the refractory. The availability of this measurement provides exciting new possibilities for process control.

This paper will show why the use of a 3.9µm camera with a borescope optic is the most accurate method for in-furnace temperature measurement. This will be done using the example of a reheat furnace where in a controlled trial using an instrumented billet the measurement from the IR device was shown to accurately track the thermocouple temperature during a variety of furnace operating conditions.

7661-22, Session 4

Rapid screening of electrochemical sensors for fossil energy applications

R. B. Dinwiddie, D. L. West, B. L. Armstrong, F. C. Montgomery, Oak Ridge National Lab. (United States)

Magnesium is being considered as a light weight substitute for steel and aluminum in automotive structures. It is important to understand the energy absorption and energy conversion characteristics of this material for crash worthiness reasons. An IR camera was used to measure the temperature of magnesium specimens during high-speed crush tests at Oak Ridge National Laboratory. The temperature evolution was compared in the rolled direction and the direction perpendicular to rolling.

7661-23, Session 5

A comparison of infrared thermography and x-ray computer tomography for the characterization of damage in composite sandwich structure

K. E. Cramer, W. C. Jackson, NASA Langley Research Ctr. (United States)

The use of composite materials continues to increase in the aerospace community. One particular application of these materials is the fabrication of a structure where core material (typically honeycomb) is sandwiched between composite face sheets. The rapid, in situ characterization of such sandwich structure has become a critical concern for the industry. In many applications it is necessary to monitor changes in this type of structure over its entire lifetime. Infrared thermography has proved to be an effective tool in the characterization of composite sandwich structures. But, interpretation of the thermography results can prove challenging. This study provides a demonstration of a situation where the thermography indicates a growth in defect size with fatigue loading, when none was expected. A comparison of the thermography results with x-ray computer tomography (CT) results is shown to provide a physical explanation for the effect.

The specimen evaluated is a composite sandwich structure with graphite-epoxy face sheets and an aluminum honeycomb core. The specimen was impacted in three locations (with each location having different physical characteristics) and then loaded in tension to failure. Infrared thermography inspections were performed after the initial impact, after one fatigue lifetime and after seven lifetimes. The single-sided flash thermography showed growth of the damage at two locations between initial impact and 1 lifetime and then stable defect size. CT imaging of the impact locations was performed after impact and after one lifetime fatigue. After one lifetime fatigue, the defect sizes measured by both techniques agree to within 10% for most defects. A physical explanation for the difference in apparent defect size, defect growth observed by thermography and the limits of the technique will be presented.

7661-24, Session 5

Active thermography signal processing techniques for defect detection and characterization on composite materials

C. Ibarra-Castanedo, Univ. Laval (Canada); N. P. Avdelidis, National Technical Univ. of Athens (Greece); M. Grenier, X. P. Maldague, A. H. Bendada, Univ. Laval (Canada)

Active thermography has been extensively investigated in the past few years for the nondestructive evaluation of different types of materials. Composites in particular have received considerable attention given that active thermography has shown to be well suited for the detection and characterization of most kinds of defects typically found in these materials such as impact damage, delaminations, disbonds and inclusions. Signal processing is a necessary step of the inspection process, especially if defect characterization is required. A wide variety of techniques have been developed from the classical thermal-based techniques to signal transformation algorithms (adapted from the area of machine vision) on which temporal data is transformed to a different domain (frequency, Hough, principal components, Laplace, high-order moments, etc.) with the purpose of simplifying data analysis. In this paper, a review of processing techniques is presented and exemplified using both academic and real composites specimens.

7661-25, Session 5

LWIR and MWIR thermography tools for composites assessment

N. P. Avdelidis, National Technical Univ. of Athens (Greece); E. Saarimäki, T. T. Kauppinen, VTT Technical Research Ctr. of Finland (Finland); A. Tati, S. Fanou, Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (Italy); M. Koui, National Technical Univ. of Athens (Greece); C. Ennaceur, TWI Ltd. (United Kingdom)

Smart methods for assessing the integrity of a composite structure are essential to both reduce manufacturing costs and out of service time of the structure due to maintenance. Nowadays, thermal non-destructive testing (NDT) is commonly used for assessing composites. This research work evaluates the potential of various infrared thermography (IRT) approaches for assessing different types of fabricated defects (i.e. impact damage, inclusions for delaminations, etc) on Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP) plates. Measurements were performed using LWIR and three active approaches: a) pulsed thermography using the flash method (xenon flash lamps), b) transient thermography using IR-heating pulse, and c) thermographic inspection for cooled sample by freezing in -20 °C and then use monitoring. Furthermore, integrated flash thermography by employing a MWIR system was also used.

7661-26, Session 5

Comparative study for the nondestructive testing of advanced ceramic materials by infrared thermography and holographic interferometry

S. Sfarra, Univ. degli Studi dell'Aquila (Italy); C. Ibarra-Castanedo, A. H. Bendada, X. P. Maldague, Univ. Laval (Canada); D. Ambrosini, D. Paoletti, Univ. degli Studi dell'Aquila (Italy)

Advanced ceramic materials are increasingly employed in varied and new applications where improved electrical, mechanical and/or thermal properties are sought. For instance, in a manner similar to carbon or glass fiber reinforced plastics, ceramic matrix composites (CMCs) are designed to improve the naturally brittle characteristics of the monolithic ceramics thanks to the inclusion of fibers. Among the main interests for advanced ceramics are the increase in the operation temperature of components, the elimination of the use of cooling fluids, and weight savings. In this paper, the capabilities of infrared thermography and holographic interferometry are investigated and compared for the nondestructive assessment of advanced ceramic materials using three experimental specimens: (1) a monolithic ceramic tile with fabricated defects, (2) a CMC specimen (from production reject) with a porous alumina matrix reinforced with glass fibers, and (3) a sandwich structure consisting on a carbon fiber honeycomb core with a ceramic plate bonded in one side.

7661-27, Session 5

Thermographic NDT data using extended-pulse excitation

S. M. Shepard, T. Ahmed, Thermal Wave Imaging, Inc. (United States); W. R. Davis, Fleet Readiness Ctr. East (United States)

The signal processing that enables quantitative analysis in modern flash thermography is typically based on a delta-function excitation model, requiring precise control of the flash pulse timing, and high-speed / high-performance IR cameras. However, it is possible to achieve similar performance for many applications by extending the basic delta function model to include non-pulsed sources, and modifying the Thermographic Signal Reconstruction (TSR) method accordingly. Under these relaxed conditions, we have used a modified TSR algorithm, combined with inexpensive uncooled cameras and simple heat sources to obtain results that compare favorably to full-scale flash results. The extended source approach involves some trade-off in terms of quantitative measurement performance, but it allows implementation of extremely portable, low-cost systems tailored specifically to application requirements.

7661-28, Session 5

Two-dimensional thermal analysis of organic molecular crystals and polymeric spherulites by microscale thermography

J. Morikawa, Tokyo Institute of Technology (Japan); E. Hayakawa, ai-Phase Co., Ltd. (Japan); K. Ikuo, Seki Technotron Corp. (Japan); T. Hashimoto, Tokyo Institute of Technology (Japan)

We report on the application of the micro-scale thermography with a high-speed infrared (IR) camera equipped with an originally designed optics for the optimum wavelength 3 - 5 micron to the two-dimensional micro-scale thermal analysis in order to observe the exothermic latent heat and thermal diffusion during the phase transitions of organic molecular crystals (n- pentacosane, n- tetracosane, and n- tricosane) and polymeric spherulites of poly(ethylene oxide) (PEO). A precision temperature control with a micro alignment xyz stage was electronically

designed by using a FPGA (Xilinx) technology. A constant rate of heating and cooling, 0.1°C/min-500°C /min, was routinely used for thermal analysis under a micro-scale thermo-graphical view.

The forerunning phenomenon of phase transition was visualized as the spatial temperature fluctuation by a two-dimensional differential calculus. The differences of the spatial inhomogeneity of proceeding speed of crystallization and rotator phase transitions of n- alkanes were analyzed. The exothermic heat patterns of the lamellae growth of n- alkanes and that of the radial direction of spherulites were quantitively analyzed. The odd-even number effect of rotator phase transition of n-alkane was observed by the different exothermic heat pattern. The main points of this paper are as follows.

1. On-lamella micro-scale thermal analysis is shown on the odd and even number n-alkanes with different exothermic heat patterns in phase transitions by the time differential calculus.

2. The anisotropic growth rate of n-alkane crystalline lamellae is found in the width and the length directions.

3. The exothermic heat pattern in the radial directions during the growth of polymeric spherulite is observed.

7661-29, Session 5

Finite element analysis and neural network model for electronic hidden solder joint geometry prediction

S. Hsieh, B. Giron, Texas A&M Univ. (United States)

This paper investigates an active thermography approach to probing hidden solder joint geometry. Ten boards were fabricated with the same number of solder joints and amount of solder paste (0.061 g), but using three solder joint geometries (60°, 90°, and 120°). The 90° angle solder pin represented a normal joint, and the 60° and 120° angle pins represented abnormal solder joints. Each board was covered with another board that had three openings just big enough to allow the pin terminals to protrude. A semi-automated system was built to heat and then transfer each board set to a chamber where an infrared camera was used to scan the board as it was cooling down. Each board set underwent the heating, cooling, and scanning process for five trials. Two-thirds of the data set was used for model development and one-third for model evaluation. An artificial neural network (ANN) was constructed to predict abnormal joints given thermal data. Results suggest that solder joints with more surface area cool much faster than those with less surface area. A Finite Element Analysis (FEA) of the heating up and cooling down process consistently predicted solder geometry using the ANN with 85% accuracy. This approach can be used not only to inspect bad solder joints (i.e., low reliability) but also to mass screen for cold solder joints during BGA assembly, since the air gaps in cold solder joints may cause cold solder joints to cool more slowly than normal joints.

7661-30, Session 5

Modeling and investigation of thermomechanical parameters of frictional lining of brakes

H. Polakowski, J. Jachimowicz, T. Piatkowski, Military Univ. of Technology (Poland); R. Kajka, The Institute of Aviation (Poland); M. Sadowski, Warsaw Univ. of Technology (Poland); M. Kastek, Military Univ. of Technology (Poland)

The paper presents theoretical analysis and numerical modeling of frictional lining of breaks and their laboratory measurements. Thermal camera measurements of surface temperature distribution were performed. At given points also temperature was measured by contact temperature sensors. Special attention was done for nonuniformity of temperature distribution across break surface. The analyze of temperature distribution allow to set the relation between the temperature

nonuniformity and breaks surface imperfections. Also additional microscope thermal measurements have been done due to correlate radiant properties and microstructure of breaks materials surface. The investigations were done for two different breaks materials: composite C/C and 500/EBC. The first material is used for plane breaks, the second is used for out-road vehicle.

7661-31, Session 5

Detecting and discriminating PE and PP polymers for plastics recycling using NIR imaging spectroscopy

M. De Biasio, R. Leitner, T. Arnold, Carinthian Tech Research AG (Austria)

The recycling of polymers requires samples to be sorted according to material. It is increasingly important to distinguish even closely related materials such as high and low-density polyethylene, or different polyterephthalate materials. The mixture of materials with different melting points is especially problematic for the industry. A method for sorting samples according to their melting point would have clear economic benefits.

NIR spectroscopy is an established technique for analysing polymers such as PE and PP. Recent technical advances allow hyperspectral images in the 1.0μm to 2.5μm range to be captured with high spatial and spectral resolution. This increased resolution allows spectral features to be used for on-line sorting of samples according to their material.

The aim of this paper is to identify those spectral features that allow PE and PP samples to be detected and distinguished. A set of PE and PP samples was extracted from an industrial recycling process. The NIR spectra of the samples were measured using an FTIR lab spectrometer. Characteristic spectral features that are determined by the chemical bonds of the material were identified.

Using a chemometric model these were related to the melting point of the materials. The samples were then imaged using a NIR hyper-spectral (HS) system. The chemometric model was adapted to the HS system and used to classify the test samples. Our experimental results show that it is possible to detect and discriminate polymers using NIR HS imaging and a chemometric model. We conclude that this approach is suitable for the real-time identification of polymers in industrial recycling systems.

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Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXI

7662-01, Session 1

Modeling passive millimeter-wave imager performance for helicopter pilotage

J. P. Reynolds, K. A. Krapels, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. A. Schuetz, Phase Sensitive Innovations, Inc. (United States)

Passive millimeter wave (PmmW) imagers have become practical as tactical imagers through incremental improvements in size, weight, and power, while simultaneously increasing resolution, sensitivity and frame rate. The US Army Night Vision and Electronic Sensor Directorate (NVESD), along with the Office of Naval Research (ONR) and its contractor Phase Sensitive Innovations (PSI), investigated modeling/predicting the field performance of PmmW imaging systems. The focus of the study was the performance of PmmW imaging systems for the task of helicopter pilotage and situational awareness in degraded visual environments such as fog, rain, dust, or clouds. NVESD has successfully modeled the performance of image intensified sensors and infrared thermal imagers on helicopters for both the targeting and pilotage tasks. This study adapted those methods to PmmW imagers. Radiometric PmmW scenes and signatures were collected by PSI to determine scene, target, and background characteristics. The measured data along with prototype camera parameters were utilized within the NVESD modeling methodology to predict pilot/sensor field performance for helicopter pilotage and detection/classification of obstacles.

7662-02, Session 1

NIR small-arms muzzle flash

J. R. Montoya, S. W. Kennerly, E. Rede, U.S. Army Research Lab. (United States)

Utilization of Near Infrared (NIR) spectral features in a muzzle flash will allow for small arms detection using low cost silicon based imagers. Detection of a small arms muzzle flash in a particular wavelength region is dependent on the intensity of that emission, the efficiency of source emission transmission through the atmosphere, and the relative intensity of the background scene. The NIR muzzle flash signature exists in the relatively large silicon spectral response wavelength region of 300 nm - 1100 nm, which allows for use of commercial-off-the-shelf silicon based detectors. The alkali metal origin of the NIR spectral features in the 7.62 x 39mm round muzzle flash is discussed and the basis for the spectral bandwidth is examined, using a calculated Voigt profile. Atmospheric limitations based on NIR spectral region are investigated in relation to the NIR muzzle flash signature. Simple metrics are used to predict sensor performance based on a model of irradiance for the source, clutter, and solar background. These metrics are signal-to-noise ratio (SNR), signal-to-solar-background ratio (SSR), and signal-to-clutter ratio (SCR). This report will introduce a model of the 7.62 x 39mm NIR muzzle flash signature, based on predicted source characteristics.

7662-04, Session 1

Experimental determination of visibility modeling parameters for aircraft

E. J. Boettcher, DCS Corp. (United States); T. Maurer, U.S. Army Night Vision & Electronic Sensors Directorate (United States); S. R. Murrill, U.S. Army Research Lab. (United States); B. S. Miler, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The Federal Aviation Administration (FAA) is presently engaged in research to quantify the visibility of aircraft under two important scenarios: aircraft observed directly by human operators in air traffic control towers (ATCT's), and aircraft observed by human operators through unmanned aerial vehicle (UAV) sensors viewed through ground-based display systems. Previously, an ATCT visibility analysis software tool (FAA Vis) was developed by the U.S. Army Research Laboratory (ARL) in collaboration with the U.S. Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) and the FAA. This tool predicts the probability of detection, recognition, and identification of various aircraft by human observers as a function of range and ATCT height. More recently, a baseline version of a UAV See-And-Avoid visibility analysis software tool was also developed by the ARL, again in collaboration with NVESD and the FAA. The UAV See-And-Avoid tool provides quantitative information on the available time that a UAV operator would have to respond to a potential conflict, given a particular UAV imaging sensor/display system and a set of observation scenario parameters. Important to the calibration of these tools is the empirical determination of quantifying target discrimination difficulty criteria. Consequently, a set of human perception experiments were conducted to empirically determine the target recognition and identification discrimination difficulty criteria for a representative set of aircraft. This paper will report on the results and analyses of those experiments.

7662-05, Session 2

Design and evaluation of (urban) camouflage

M. A. Hogervorst, A. Toet, P. A. M. Jacobs, TNO Defence, Security and Safety (Netherlands)

An international group consisting of several NATO groups participated in a trial in which urban camouflage was developed and compared. First, photographs were taken in and around a small town in Arizona. Next, the different groups derived urban camouflage patterns from these photographs. We applied our method for deriving a camouflage pattern from a set of (characteristic) background images to the imagery. Eleven different patterns were made into prototype camouflage suits. Panoramic images of all prototype suits were taken on 36 locations in the environment in which the background images were taken. We used these images in a search experiment with human observers for evaluating camouflage performance of the various patterns. The pattern we developed featured among the two best performing patterns, with good performance indicated by low chance of detection and long search times. This data was also used to test various clutter models. Our results show that we have developed a method for deriving a camouflage pattern from background imagery that works well.

7662-06, Session 2

Modeling the improvement in target acquisition performance of active imaging systems using speckle reduction techniques

D. E. Oxford, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The U.S. Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate has developed a laser-range-gated shortwave infrared imaging system performance model for the detection, recognition and identification of vehicle targets. The model, called NVLRG, includes the degrading effects of speckle on target acquisition performance when using a conventional fixed-wavelength laser as the illumination source. This paper describes a speckle model that can be extended to include multi-line and wavelength-tunable laser sources. The reduced

speckle effects, and thus increased target acquisition performance, expected from this spectral diversity technique is verified through human perception testing using simulated images of the NVESD target set with various wavelengths, spectral bandwidths, image averaging and blur.

7662-07, Session 2

Performance evaluation of image enhancement techniques on a EMCCD camera

J. Dijk, P. Bijl, A. W. M. van Eekeren, TNO Defence, Security and Safety (Netherlands)

Recently new techniques for night-vision cameras are developed. Digital image-intensifiers are becoming available on the market. Also Electron Multiplying Charge Coupled Device (EMCCD) cameras are developed, which may even be able to record color information about the scene. However, in low-light situations all night-vision imagery becomes noisy. In this paper we evaluate the performance of image enhancement techniques for one type of noisy night imagery, that is a EMCCD camera. The image enhancement techniques tested are noise reduction, super-resolution reconstruction and local adaptive contrast enhancement. The results show that image enhancement techniques improve the usage of EMCCD camera's in low-light conditions.

7662-08, Session 2

Scotopic perceptual rendering of synthetic targets in digital photographs

F. Iannarilli, Jr., F. W. Bacon, J. A. Conant, Aerodyne Research, Inc. (United States); T. Deas, Army Aviation Applied Technology Directorate (United States)

Conspicuity simulation of candidate target and signage designs and paint schemes is a cost-effective means for selection. However, to simulate unaided night (scotopic) viewing, we appropriately modify the typical image synthesis and visual jury display to emulate scotopic percepts, including the Purkinje effect (blue shift) and luminance-dependent reduction of brightness and acuity. Furthermore, our process includes a day-for-night computation that allows convenient employment of daytime-acquired digital color photographs as backgrounds into which targets are inserted. We demonstrate this scotopic simulation capability as applied to an evaluation of helicopter paints. We also compare the predicted imagery to scale model field measurements.

The helicopter signatures are computed using a US government-standard 3D model. The day-for-night process takes a color digital photograph and estimates the scotopic V' band image from a suitable spectral mixture of the R,G, and B channels. Guided by signature model calculations, the resulting V' image is subsequently scaled to night luminance units compatible with the target signature calculation. We demonstrate the validity of this process, for similar solar and lunar angles, using matching day and night photographs. We employ the revised Tumblin-Rushmeier algorithm, which employs the brightness-luminance relations of Stevens, to tone-map the resulting scotopic luminance image. The tone-mapped image is presented on a conventional display under indoor photopic conditions, emulating the perceptual loss of brightness and contrast. Additionally, we employ luminance-dependent bilateral spatial filtering to simulate loss of acuity. Importantly, this filtering maintains sharp edges while blurring lower-contrast detail, in keeping with visual perception.

7662-40, Poster Session

Review of Bayer-pattern CFA demosaicking with new quality assessment algorithms

R. A. Maschal, Jr., S. Young, U.S. Army Research Lab. (United States); J. P. Reynolds, K. A. Krapels, J. D. Fanning, T. Corbin, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Given the frequent lack of a reference image or ground truth when performance testing Bayer pattern color filter array (CFA) demosaicing algorithms, two new no-reference quality assessment algorithms are proposed. These new quality assessment algorithms give a relative comparison of two demosaicing algorithms by measuring the presence of two common artifacts in their output images. For this purpose, various demosaicing algorithms are reviewed, especially adaptive color plane, gradient based methods, and median filtering, with particular attention paid to the false color and edge blurring artifacts common to all demosaicing algorithms. Classic quality assessment methods which require a reference image, such as MSE, PSNR, and ΔE, are reviewed, their typical usage characterized, and their associated pitfalls identified. With this information in mind, the motivations for no reference quality assessment are discussed. The new quality assessment algorithms are then designed for a relative comparison of two images demosaiced from the same CFA data by measuring the sharpness of the edges and determining the presence of false colors. Demosaicing algorithms described earlier are evaluated and ranked using these new algorithms. A large quantity of real images is given for subjective evaluation. These images are also used to justify those rankings suggested by the new quality assessment algorithms. This work provides path forward for future research investigating possible relationships between CFA demosaicing and color image super-resolution.

7662-42, Poster Session

D8: an image capturing software for advanced applications including temporal synchronization of imaging sensors

S. Cronström, T. Svensson, I. G. Renhorn, Swedish Defence Research Agency (Sweden)

A flexible tool for collecting data from imaging sensors is presented. It is Windows XP compatible and designed to meet demanding requirements in scientific applications. It has been evaluated both in laboratory measurements and extended field trials. Main features of the image capturing software, denoted D8, are:

- D8 supports various kinds of cameras: monospectral, multispectral and hyperspectral. A new camera is included by adding additional information in a configuration list.

- The image data acquired from D8 is standardized into one format based on the ENVI format.

- Each single image gets a timestamp with the precision 1 ms. There is support for an FPGA board, which can improve the resolution to 1 µs.

- Through D8 an arbitrary number of cameras can be temporally synchronized and the image data collected. This option imitates true multi-colour cameras.

Results from a temporal synchronization and spatial alignment of two multiband cameras are presented.

7662-43, Poster Session

Performance evaluation of FIR camera systems applied to pedestrian detection

S. Franz, R. Schweiger, O. Löhlein, Daimler AG (Germany); D. N. Willersinn, K. Kroschel, Fraunhofer-IOSB (Germany)

Besides resolution, an important performance parameter and cost driver of a FIR camera is the sensitivity. It depends on the sensitivity of the detector array itself and the characteristics of the optic. The effects of the optic are considerably driven by the f-number, with high values resulting in decreased sensitivity, but providing the possibility for simple lens

design and cheaper production costs. The impact on the resulting image quality and eventually on the detection performance of a recognition system depends on the task at hand. The same applies for predicting image quality and system performance. The goal is to have an image quality measure that allows for the assessment of how the changes in the sensor data influence the detection performance.

In this contribution 4 different sensor setups with different optics and f-stops are evaluated to measure the effects on image quality and their impact on the performance of a pedestrian recognition system for road vehicles.

In order to eliminate the influence of external parameters, we use data of real world road scenarios with pedestrians, collected simultaneously with several cameras mounted in parallel in a test vehicle, during multiple measuring campaigns. This allows for a direct analysis and comparison of the different sensors and their impact on image quality and the detection performance.

Finally, this will help with the task to determine the maximal reasonable degradation and with it a noticeable cost reduction of a sensor and still maintain a sufficient data quality for the task of the recognition system.

7662-44, Poster Session

Estimation of radiant intensity and average emissivity of Magnesium/Teflon/Viton (MTV) flares

L. B. Magalhaes, F. D. P. Alves, Instituto Tecnológico de Aeronáutica (Brazil)

This paper presents a comparison between measurements of the spectral radiant intensity of MTV (Magnesium/Teflon®/Viton®) flares and theoretical estimation using available mathematical models in the range of 0.4 µm up to 14.5 µm. It is used an indigenous system capable of hold the flare pellets in the same position during the burning time and reproduce the airflow after an actual air launching at different velocities. Two mathematical models are studied and adapted to predict MTV flare radiant intensity and average emissivity from visible to long wavelength infrared. The results indicate that the adapted models can be use to estimate the MTV flare parameters in different situations with good accuracy.

7662-45, Poster Session

A comparison of fan-beam and pencil-beam scatterometers for satellite remote sensing systems

S. Lang, National Satellite Ocean Application Service (China)

Spaceborne microwave scatterometers can provide global, all-day, high-accuracy, high-resolution and short cycle sea surface wind data.

With different formations of the spatial resolution, spaceborne scatterometers are divided into two categories: fan-beam and pencil-beam. By theoretical analysis and comparison of simulation results, the following comparing results of the two scatterometer categories are summarized. a) The positions of wind vector cells in the swath of pencil-beam scatterometers are relatively immovable. And each cell only contains measurement information with 2 or 4 incident angles. These characteristics of pencil-beam scatterometers are not of benefit to the retrieval of wind directions. Fan-beam scatterometers can obtain more measurement information with more incident angles and different combinations of these incident angles. This benefits fan-beam scatterometers to the retrieval of wind directions. b) The antenna gain of pencil-beam scatterometer systems is higher than fan-beam scatterometer systems. Also, the signal noise ratio (SNR) of pencil-beam systems is better than fan-beam systems. As a result, pencil-beam scatterometers have better performance than fan-beam scatterometers on the retrieval of low wind speed. c) From the comparison of system structure, the antenna of pencil-beam scatterometers is larger and

heavier. Also, pencil-beam scatterometers have bigger antenna rotational angular momentum. For these reasons, pencil-beam scatterometer systems have more limiting factors for antenna servos.

As the conclusion of this paper, fan-beam scatterometers at Ku-band have better performance in wind retrieval compared to pencil-beam scatterometers for minisatellite platforms. However, because the antenna of fan-beam scatterometers has lower gain, which leads to lower SNR of return signals, the subsequent data processing algorithms for fan-beam scatterometers are more complicated.

7662-09, Session 3

Flat panel displays for military imaging applications

S. P. Atwood, L. Collier, Azonix Corp. (United States)

With the wide range adoption of Active Matrix Liquid Crystal technology for practically every display application comes the opportunity to use commercial off-the-shelf (COTS) panels for Infrared and Medical Imaging applications. In fact, many successful wide dynamic range and high resolution medical imaging AMLCD displays are in practical use today for radiology and MRI applications. However, the military and night vision community has been slow to adopt similar technology for display of Infra-Red imaging data in mission critical applications, showing the same preference for CRTs as the radiology community once did for film based images.

One of the reasons for this concern is the differences between an inherently analog based display system versus a digital discrete matrix display system.

In this paper we will address the basic performance characteristics of high performance AMLCD panels, the challenges and opportunities presented by the analog to digital acquisition process and the methods that can be used to produce maximum dynamic range and spatial resolution from IR sensor images. With the right methods and design considerations a system that rivals or exceeds analog CRT performance can be achieved in most aspects

This paper will also address the considerations for the ambient environment of the observer and describe methods for optimizing viewability under sunlight versus in-doors and dark-room conditions. The light adaptation behavior of the human visual system with be discussed and it will be shown how this can have a significant influence on the perception of gray levels in wide dynamic range images.

7662-10, Session 3

Comparing masked target transform volume (MTTV) clutter metric to human observer evaluation of visual clutter

H. A. Camp, EOIR Technologies, Inc. (United States); S. K. Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States); R. Moore, U.S. Army Redstone Technical Test Ctr. (United States)

The Night Vision and Electronic Sensors Directorate's current time-limited search model, which makes use of the targeting task performance metric to describe imager quality, does not explicitly account for the effects of visual clutter on observer performance. The time-limited search model is currently based on empirical fits to describe human performance for a time of day, spectrum, and environment. Incorporating a clutter metric into the time-limited search model may reduce the number of these empirical fits needed. The Masked Target Transform Volume (MTTV) clutter metric has been previously presented and compared to other clutter metrics. Using real infrared imagery of rural and urban scenes with varying levels of clutter, NVESD is currently evaluating the appropriateness of the MTTV metric. NVESD had twenty-three subject matter experts (SME) rank the amount of clutter in each scene in a series of pair-wise comparisons. MTTV metric values were calculated and then

compared to the SME rankings. The MTTV metric ranked the clutter in a similar manner to the SME evaluation, suggesting that the MTTV metric may emulate SME response. This paper is a first step in quantifying clutter with agreement to human evaluation.

7662-11, Session 3

Analytical model quantifies the military benefit of collaborative search

M. H. Friedman, T. W. Du Bosq, E. A. Flug, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

An analytical model has been developed that quantifies the military benefit of having multiple observers search a field of regard. The model suggests considerable benefits accrue from collaborative search: with ten observers the mean detection time is reduced by almost an order of magnitude compared to that of a single observer while the probability of detection is substantially increased over that of a single observer. With regard to validation, computer simulations are in agreement with the analytical model and perception tests done by military observers are planned. The model is expected to find use in wargaming and for evaluating the efficacy of networked imaging sensors.

7662-12, Session 3

Triangle search experiment to isolate scene clutter effects

R. K. Moore, U.S. Army Redstone Technical Test Ctr. (United States); H. A. Camp, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. E. Halford, The Univ. of Memphis (United States)

A perception experiment was performed in an effort to measure the effect of clutter on search performance while keeping target size, target contrast, and system bandwidth constant. In the NVESD time-limited search model, detection performance is said to only vary with changes in the product of target size and target to background contrast, if the imaging system and the time limit are left constant. The results of this experiment show that changes in scene clutter produce changes in detection performance when these other factors remain unchanged, thereby making a stronger case for the inclusion of a clutter metric into the NVESD TLS model. When using real imagery, it is difficult to find good examples of change in clutter without changes in target size, contrast, noise, or other factors also being present. Using computer generated imagery of triangles and tilted squares allowed the clutter aspect of search to be experimentally isolated. When applied to imagery in the perception experiment, the masked target transform volume clutter metric was shown to correlate well with the average observer response time.

7662-13, Session 4

Modeling performance using sensor simulation and image metrics

J. D. Fanning, J. P. Reynolds, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

This paper presents progress on image-space performance metrics designed to match the performance of a human doing a target identification task. This will allow modeling of non-linear image processing operations that do not easily fit into linear performance models such as NVThermIP. The original image is produced by blurring and downsampling a high quality image to produce an image that will match the output of a given linear camera system. This image can then be processed by any type of non-linear image processing algorithm such as local area contrast enhancement. We apply various performance

metrics to the resulting image and attempt to correlate the metrics to human observer performance. This effort is intended as work toward a synthetic observer model that can be used to estimate the range performance of a system using arbitrary image processing.

7662-14, Session 4

Effectiveness assessment of signal processing in the presence of smear

P. Bijl, TNO Defence, Security and Safety (Netherlands); J. A. Beintema, J. Dijk, N. van der Leden, TNO Defense, Security and Safety (Netherlands)

Moving imagery from a static scene was recorded at nine different angular velocities ranging from 0 (static) to 1 pixel/frame using a tilted rotating mirror. The scene contained a thermal acuity test chart with triangular test patterns based on the Triangle Orientation Discrimination (TOD) test method. The imagery were processed with different types of imagery enhancement: DRS (dynamic super resolution), LACE (local adaptive contrast enhacement) and combinations. DSR shows a significant improvement in Visual Acuity at low velocities but its effect decreases at higher velocities where smear becomes apparent. Performance with LACE is equal to optimized gain and level setting by hand. Visual Acuity at 0.57 p/frame containing significant smear were compared with the identification performance data for two-hand held systems collected under the same conditions. The ratio M75 between the 75% correct threshold size for the two-hand held objects and TOD triangle threshold size is preserved under all conditions measured. Thus TA range predicted on the basis of the TOD is robust against a complex combination of conditions, including motion, smear and the types of image enhancement applied.

7662-15, Session 4

Next-generation model for EO/IR system performance

B. P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The next generation of Army imager performance models is currently under development at NVESD. The aim of this new model is to provide a flexible and extensible engineering tool for system design which encapsulates all of the capabilities of the existing Night Vision model suite (NVThermIP, SSCamIP, etc) along with many new design tools and features including a more intuitive interface, the ability to perform trade studies, and a library of standard and user generated components. By combining the previous model architectures in one interface the new design is better suited to capture emerging technologies such as fusion and new sensor modalities. In this paper we will describe the general structure of the model and some of its current capabilities along with future development plans.

7662-16, Session 4

Readout IC requirement trends based on a simplified parametric seeker model

T. D. Osborn, Sandia National Labs. (United States)

Modern space based optical sensors place substantial demands on the focal plane array readout integrated circuit. Active pixel readout designs offer direct access to individual pixel data but require analog to digital conversion at or near each pixel. Thus, circuit designers must create precise, fundamentally analog circuitry within tightly constrained areas on the integrated circuit. Rapidly changing phenomena necessitate tradeoffs between sampling and conversion speed, data precision, and heat generation adjacent the detector array, especially of concern

for thermally sensitive space grade infrared detectors. A simplified parametric model is presented that illustrates seeker system performance and analog to digital conversion requirements trends in the visible through mid-wave infrared, for varying sample rate. Notional limiting-case Earth optical backgrounds were generated using MODTRAN4 with a range of cloud extremes and approximate practical albedo limits for typical surface features from a composite of the Mosart and Aster spectral albedo databases. The dynamic range requirements imposed by these background spectra are discussed in the context of optical band selection and readout design impacts.

7662-17, Session 5

Adaptive design and visual perception experiments: standards, guinea pigs, and planning for unforeseen confounds

J. D. O'Connor, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Meticulous experimental design may not always prevent confounds from affecting experimental data acquired during visual perception experiments. Although experimental controls reduce the potential effects of foreseen sources of interference, interaction, or noise, they are not always adequate for preventing the confounding effects of unforeseen forces. Visual perception experimentation is vulnerable to unforeseen confounds because of the nature of the associated cognitive processes involved in the decision task. Some confounds are beyond the control of experimentation, such as what a participant does immediately prior to experimental participation, or the participant's attitude or emotional state. Other confounds may occur through ignorance of practical control methods on the part of experiment's designer. The authors conducted experiments related to experimental fatigue and initially achieved significant results that were, upon re-examination, attributable to a lack of adequate controls. Re-examination of the original results and the processes and events that led to them yielded a second experimental design with more experimental controls and significantly different results. The author proposes that designers of visual perception experiments can benefit from planning to use a test-fix-test or adaptive experimental design cycle, so that unforeseen confounds in the initial design can be remedied.

7662-18, Session 5

New target acquisition task for contemporary operating environments: personnel in MWIR, LWIR, and SWIR

E. J. Boettcher, DCS Corp. (United States); K. R. Leonard, V. A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate (United States); D. D. Acton, Raytheon Co. (United States)

Operating environments that US Soldiers are in have changed, along with the types of tasks that Soldiers are required to perform. In addition, the potential imaging sensor options available have increased. These changes make it necessary to examine how these new tasks are affected by waveband and time of day. US Army Research, Development and Engineering Command, Communications Electronics Research Development and Engineering Center, Night Vision and Electronic Sensor Directorate (NVESD), investigated one such task for several wavebands (MWIR, LWIR, Visible, and SWIR) and during both day and night. This task involved identification of nine different personnel targets: US Soldier, US Marine, Eastern-European/Asian Soldier, Urban Insurgent, Rural Insurgent, Hostile Militia, Indigenous Inhabitant, Contract Laborer, and Reporter. These nine distinct targets were made up from three tactically significant categories: Friendly Force, Combatant and Neutral/Non-Combatant. A ten second video imagery was taken of an actor dressed as one of these targets. The actors walk in a circle, enabling all aspects to be seen in each video clip. Target characteristics were measured and characteristic dimension, target contrast tabulated. A nine-alternative,

forced choice human perception test was performed at NVESD with Marines observers. This test allowed NVESD to quantify the ability of observers to discriminate between personnel targets for each waveband and time of day. The task difficulty criterion, V50, was also calculated allowing for future modeling using the NVESD sensor performance model.

7662-19, Session 5

Image fusion algorithm assessment using measures of complementary and redundant information

C. L. Howell, The Univ. of Memphis (United States) and U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. E. Halford, K. A. Krapels, The Univ. of Memphis (United States); R. G. Driggers, Office of Naval Research (United States)

Imagery of the same scenes in different spectral bands often contain various amounts of complementary information between them; therefore when fused, an increase in information transfer occurs allowing for improved human performance. The goal of this effort is to determine the effectiveness of using measures of the complementary frequency information content in each source image as a way to assess fusion algorithm performance. Human perception experiments using fused imagery of standard military targets are performed to evaluate the performance benefit of each image fusion algorithm. A performance metric, based on mutual information, is developed to investigate the correlation between complementary information and improved task performance. The preliminary results of this study show that the performance metric can successfully be used to rank image fusion quality and suggest that the metric can also be used with predicting improved task performance.

7662-20, Session 5

Multivariate perception testing for fire-service thermal imager evaluations

F. K. Amon, National Institute of Standards and Technology (United States)

This work provides an answer to the question "How good does the image need to be?" for testing image quality of fire service thermal imagers. Fire fighters were asked to identify potential fire hazards in 4500 images that had been degraded in brightness, contrast, spatial resolution, and noise level. A perception model was built from the resulting data. The methods of degrading the images used to develop the perception model were mathematically related to methods employed in objective laboratory-scale image quality testing. Thus, the perception model could be used to establish pass/fail criteria for objective laboratory-scale image quality tests of nonuniformity, spatial resolution, and effective temperature range for fire service thermal imagers. The perception model was applied to images that were collected using a high resolution visible camera focused on the thermal imager's display while the thermal imager viewed a variety of thermal targets. In this way, the subjectivity of human perception testing is applied equally to all thermal imagers being tested for compliance to standardized image quality test methods. As fire service imaging needs and test methods evolve, the perception testing can be updated with different image types and scenarios.

7662-21, Session 6

Analysis of participant variance to improve the efficiency of sensor modeling perception experiments

J. D. O'Connor, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Night Vision and Electronic Sensors Directorate (NVESD) Modeling and Simulation Division (MSD) sensor models, such as NV Therm IP, are developed through perception experiments that investigate phenomena associated with sensor performance (e.g. sampling, noise, sensitivity). A standardized laboratory perception testing method developed in the mid-1990's has been responsible for advances in sensor modeling that are supported by field sensor performance experiments.The number of participants required to yield dependable results for these experiments could not be estimated because the variance in performance due to participant differences was not known. NVESD and George Mason University (GMU) scientists measured the contribution of participant variance within the overall experimental variance for 23 individuals each exposed to 1008 stimuli. Results of the analysis indicate that the total participant contribution to overall experimental variance was between 1% and 2%.

7662-22, Session 6

Masked target transform volume clutter metric applied to vehicle search

R. K. Moore, U.S. Army Redstone Technical Test Ctr. (United States); H. A. Camp, S. K. Moyer, U.S. Army Night Vision & Electronic Sensors Directorate (United States); C. E. Halford, The Univ. of Memphis (United States)

The Night Vision and Electronic Sensors Directorate's current time-limited search model, which makes use of the targeting task performance metric to describe imager quality, does not explicitly account for the effects of clutter on observer performance. The masked target transform volume clutter metric has been presented previously, but is first applied to the results of a vehicle search perception experiment here. NVESD's Electro-Optical Simulator program was used to generate hundreds of synthetic images of tanks hidden in a rural environment. 12 observers searched for the tanks and their performance is compared to the MTTV clutter level, signal to clutter ratios using several clutter metrics from open literature, and to the target size-contrast product (currently used by the TTP to measure target saliency). The investigated clutter metrics included the Schmeider-Weathersby statistical variance, Silk's statistical variance, Aviram's probability of edge detection metric, and Chang's target structural similarity metric. The MTTV was shown to better model observer performance as measured by the perception experiment than any of the other compared metrics, including the target size-contrast product.

7662-23, Session 6

Improved target signature definition for modeling performance of high-gain saturated imagery

T. W. Du Bosq, U.S. Army Night Vision & Electronic Sensors Directorate (United States); B. L. Preece, EOIR Technologies, Inc. (United States)

The standard model used to describe the performance of infrared sensors is the U.S. Army thermal target acquisition model, NVThermIP. The model is characterized by the contrast of the target and the resolution and sensitivity of the sensor. Currently, manual gain and level determine optimal contrast for military targets. The Night Vision

models are calibrated to such images using a spatial average contrast consisting of the root sum squared of the difference between the target and background means and the standard deviation of the target internal contrast. This definition of contrast applied to the model will show an unrealistic increase in performance for saturated targets. This paper presents a modified definition of target contrast for use in NVThermIP, including a threshold value for target to background mean difference and the effect of saturated pixels in the standard deviation of the target. Human perception experiments were performed and the measured results are compared with the predicted performance using the modified target contrast definition in NVThermIP.

7662-24, Session 6

Resolution and sensitivity: simplified imager performance by MTF and PTC

J. A. Mazzetta, S. D. Scopatz, Electro Optical Industries, Inc. (United States)

How to quantify something that is typically subjective in nature can be a daunting task. Image quality is no exception and the pursuit of quantifiable results has thus led to an exhaustive battery of tests, methodology, and reporting formats. How many specifications are really required of a camera to establish its imaging performance? Of these which are actually pertinent and further which are truly unique? Most all design decisions can eventually be reduced down to a simple tradeoff. Whether it be, for example, weight versus strength or cost versus reliability there is always a struggle to be had at some point during the design process. For sensor makers this tradeoff typically manifests as resolution versus sensitivity. Who cares if you have a 100 mega pixel sensor if the pixels are not sensitive enough to respond to reasonable illumination. On the other hand who cares if you can image with virtually no light but don't have enough pixels to resolve your subject. Resolution and sensitivity are essential to ascertaining imager performance. This paper will discuss how these two specifications are more than just a mega pixel count or simply an ISO film speed equivalent. Resolution of a sensor is best reported as its modulation transfer function (MTF) and sensitivity is much more informative in terms of a photon transfer curve (PTC). This paper will show how to create and interpret these two curves and finally how to translate the results back into the qualitative realm.

7662-25, Session 6

Clutter effects on airborne tracking resolution requirements for urban vehicles

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This paper details the development, experimentation, collected data and the results of research designed to gain an understanding of the effects of clutter on the temporal and spatial image collection guidelines for tracking urban vehicles. More specifically, a quantitative understanding of the relationship between human observer performance and the spatial and temporal resolution is sought. Performance is measured as a function of the number of video frames per second, imager spatial resolution and the ability of the observer to accurately determine the destination of a moving vehicle target as it encounters vehicles with similar infrared signatures. The research is restricted to data and imagery collected from altitudes typical of modern low to mid altitude persistent surveillance platforms using a wide field of view. The ability of the human observer to perform an unaided track of the vehicle was determined by their completion of carefully designed perception experiments. In these experiments, the observers were presented with simulated imagery from Night Vision's EOSim urban terrain simulator. The details of the simulated targets and backgrounds, the design of the experiments and their associated results are included in this treatment.

7662-26, Session 7

Evaluation tools for the effectiveness of infrared countermeasures and signature reduction for ships

R. M. Schoemaker, R. H. M. A. Schleijpen, TNO Defence, Security and Safety (Netherlands)

The protection of ships against infrared guided missiles is a concern for modern naval forces. The vulnerability of ships can be reduced by applying countermeasures such as infrared decoys and infrared signature reduction. This paper will present a set of simulation tools which can be used for assessing the effectiveness of these measures. The toolset consists of a chain of models which calculate the infrared signature of a ship (EOSM), generate an infrared image of the ship in a realistic sea and sky background (EOSTAR) and determine the behaviour of an infrared missile seeker against these images and simulate the complete missile fly-out including countermeasure deployment (EWM). All model components will be discussed. Typical simulation runs will be shown.

7662-27, Session 7

CART IV: improving automatic camouflage assessment with assistance methods

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In order to facilitate systematic improvements of camouflage and concealment assessment methods, the software system CART (Camouflage Assessment in Real-Time) was built up to process VIS, IR and SAR image sequences (see SPIE 2007, 2008, and 2009). It comprises a semi-automatic marking of target objects (ground truth generation) including their propagation over the image sequence and the evaluation via user-defined feature extractors. The conspicuity of camouflaged objects due to their movement can be assessed with a purpose-built processing method.

This article presents the enhancements over the recent year and addresses several procedures to assist the camouflage assessment and to extend it to a broader application range. For example, some very noisy infrared image data material can be evaluated for the first time by applying the presented methods which fathom the correlations between camouflage assessment, MTI (moving target indication) and tracking procedures as well as dedicated noise filtering.

7662-28, Session 7

Urban scene simulation for multimodal sensing applications

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One of the biggest challenges in developing and testing algorithms based on multi-modal sensing has always been the limited volume of data and the difficulty in collecting additional data. This need has become particularly acute for examining personnel detection and tracking algorithms for urban scenarios. In order to produce the necessary volume of data and images for urban environments, a scalable database scheme has been implemented to manage object location and orientation, scene dynamic processes, and multiple signature modalities. A database scheme was adapted to enable multiple signature models to be employed in the scene simulation process. The scene elements are stored in the Scene-Simulation Database. Static elements are placed in the scene at the desired location and orientations; dynamic elements, such as humans and vehicles, are modeled using an integrated animation system. Both scene element types can have multimodal time evolving signatures. To handle the scene and signature dynamics, the database

is capable of receiving motion or multi-modal signature data from first principle based algorithms or from direct input of measured data, allowing for greater versatility. Both visualization and image rendering routines have been developed that directly access the database to aid in scene creation and image sequence generation. These routines are capable of generating image sequences for different sensing modalities and varying sensor locations to emulate realistic sensor positioning for use in development and testing of algorithms based on multi-sensor data. This paper will outline the approach and development of the scene database and present example multi-modal imagery and video sequences. An algorithm development application will also be presented.

7662-29, Session 7

Simulation of active EO imaging system based on SE-WORKBENCH and OSMoS software tools

T. Cathala, A. Joly, N. Douchin, OKTAL Synthetic Environment (France); T. Meynard, A. Yatsou, ATIS (France)

Active EO imaging system are more and more considered as a good solution for detection/recognition or guidance purposes in severe conditions such as very foggy atmospheric conditions or in the presence of smoke due to the use of flares consisting in smoke-producing devices. Especially flash laser systems that have range gating capabilities enable to eliminate the photons that are backscattered to the sensor by the particles in the atmosphere and hence to improve the detection performances of the system. Range gated systems also offer recognition/ identification capabilities based on the identification of the shape of a target. Thus it is of great interest to be able to assess the performances of such systems in different operationnal conditions and simulation is a good candidate for that.

The SE-WORKBENCH workshop, also called CHORALE (French acceptation for "simulated Optronic Acoustic Radar battlefield") is used by the French DGA to perform multi-sensors simulations. CHORALE enables the user to create virtual and realistic multi spectral 3D scenes, and then generate the physical signal received by a sensor, typically an IR sensor.

Taking advantage of developments made in the frame of Radar simulation, CHORALE is currently enhanced with new functionalities in order to tackle the "active" problem, involving new generation infrared sensors such as laser.

OSMoS is a development software workshop with a suite of modules that allow customers to rapidly develop and deploy mathematically accurate, physics-based, sensor and scene simulation applications. OSMoS gives the user valuable information that can substantially increase the performance and decrease costs of complete optronic systems.

In the active domain, all the physical phenomena are taken into account: laser-sensor coupling, propagation, attenuation, Modulation Transfer Function (MTF), scattering etc. Validated sight laser detection models are available. OSMoS also offers an innovative stochastic tool providing false alarm and detection performances by propagating probability density functions through the model.

The aim of this paper is to demonstrate that combining the SE-WORKBENCH and OSMoS software tools is an adequate solution for the simulation of an active EO imaging system since it allows one to take into account all the main features that are the attenuation and scattering due to the atmospheric propagation, effects due to the atmospheric turbulence on both the laser illumination beam and the sensor imaging process and the speckle effects due to the phase coherence of the laser source. The distribution of these features between both software tools is discussed in the paper.

7662-30, Session 7

The use of SE-WORKBENCH for aircraft infrared signature, taken into account body, engine, and plume contributions

T. Cathala, N. Douchin, A. Joly, OKTAL Synthetic Environment (France); S. Perzon, Go Virtual Nordic AB (Sweden)

The IR signature of an aircraft is the result of several major contributions, namely:

- Hot engine parts of the tail pipe and/or the air intakes

- Combustion hot gases (and in some cases hot carbon particles) in the plume

- Skin of the airframe, due to the thermal emission resulting from aerodynamic heating and internal heat sources and the reflected ambient radiation from the sun, the sky and the ground.

The aim of this paper is to explain how the combination of Computational Fluid Dynamics (CFD) models (FLUENT, CFD++ or others), RadTherm-IR, 3D thermal computational code and SE-WORKBENCH from OKTAL-SE is an adequate solution for computing the IR signature of a jet aircraft taking all this major into account.

An F16 fighter jet has been simulated by a CFD code including a multi species gas with the plume included in the CFD simulation. The engine intake is simulated as a mass outlet and the engine exhaust was treated as a mass inlet with a typical mixture of species that represents the state of the gases after the combustion in the jet engine. The correct temperature of the gases are imposed at this boundary and the plume is then just what will be advected downstream including turbulence dispersion and mixing. The mesh is a tetrahedral mesh with prism layers on the surface. Wall functions boundary conditions were used at the walls and a free stream boundary condition was used at the outer boundary. The results were exported using the built in CGNS or ASCII export and this was imported into SE-WORKBENCH.

The solution adopted for computing the radiative transfer through the plume is based on the IRMA module of the NIRATAM software package. The radiation from hot gases is computed using SLG (Single-Line-Group) or MLG (Multi-Line-Group) band model depending on the temperature along the LOS and the Curtis-Godson approximation is used for the mean transmissivity through inhomogeneous gases. The IRMA implementation has been revisited to make faster and more easy to maintain and the new plume radiative transfer module has been extended in terms of the number of species and the spectral resolution.

Then the revisited and extended version of IRMA has been integrated in the non real time rendering module of the SE-WORKBENCH, SE-RAY-IR, for computing IR images of jet plumes taking into account the atmosphere between the sensor and the plume but also the presence of clouds on the LOS between the sensor and the plume. Especially for computing properly the atmospheric propagation along a LOS that intersects the plume SE-ATMOSPHERE module is used for pre-computing high spectral resolution atmospheric radiation data.

The paper illustrates the use of SE-RAY-IR for computing the IR signature of the F16, including the plume, either as an isolated target in the sky or with the background behind. The paper also explains how we can render the aircraft with its plume in real time using SE-FAST-IR and a pre-computation of the plume with SE-RAY-IR.

7662-31, Session 7

IR susceptibility of naval ships using ShipIR/NTCS

D. A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada)

Methods of analysing the signature and susceptibility of naval platforms to infrared detection are discussed. An unclassified ShipIR destroyer model is used to illustrate the primary sources of infrared signature and detection: the exhaust system, solar-heating, and operating climate. The basic detection algorithm used by the Naval Threat Countermeasure

Simulator (NTCS) component of ShipIR is described and used to analyse the effectiveness of stealth technologies, such as stack suppression, low solar absorptivity (LSA) paints, and Active Hull Cooling (AHC). Standard navy climatic data and statistics are analysed to determine a minimum (5%), average (50%) and maximum (95%) signature condition for each geographic location. The change in detection range of two sensor wave-bands (3-5, 8-12) operating at two altitudes (10m, 270m) in each of the specified climates is used to determine the effectiveness of each stealth solution, alone or in combination, providing a more integral approach to the design of a stealthy infrared ship. These methods and tools form the basis on which to evaluate new platform designs, and future efforts to incorporate other sensor and observer effects are also discussed.

7662-32, Session 7

Novel methodologies for the measurement of atmospheric turbulence effects

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Atmospheric turbulence is a complex nonlinear phenomenon in imaging that introduces blur, distortion, and intensity fluctuations that corrupt image quality and can lead to poor target acquisition performance. The modeling of imaging sensors requires an accurate description of turbulence effects. To date, the U.S. Army RDECOM CERDEC NVESD sensor performance models characterize the effect of turbulence as a simple MTF. In this paper, we present two novel methodologies for the measurement of the turbulence MTF in infrared imagery. First, the structural similarity metric is used to compare pristine and degraded imagery to iteratively extract an equivalent blur. Second, contrast modulations of radial bar targets are analyzed to extract an equivalent blur. Human perception tests are compared against model predictions. The results show that complex turbulence effects can be effectively modeled with simple MTF blurs. These techniques will advance the characterization of atmospheric effects in sensor performance models.

7662-33, Session 8

Evaluation of a method to radiometric calibrate hot-target image data by using simple reference sources close to ambient temperatures

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To perform radiometric calibrations of image data, reference sources are needed in order to acquire data at two or more radiance levels giving the calibration parameters. Due to sensor drift for detectors in the infrared region the parameters have to be frequently recalculated during an extended signature measurement if the accuracy is to be maintained. In signature measurements where the incident radiance levels from hot targets are exceeding the background by many orders of magnitude the reference sources need to emit radiation at high radiance levels. Such reference sources are more complex and so are the handling of these sources. The calibration procedure tends to become impractical in field trials where several spectral bands are involved, which increases the need for reference data and the number of reference sources. A method to radiometric calibrate hotspot target data by using only a few simple reference sources close to ambient temperatures has been evaluated in this paper. Reference data has been collected both in laboratory studies and in field trials at various weather conditions. The accuracy and the precision of the method are presented. The uncertainty due to sensor drift is estimated. Error sources connected to the calibration method are discussed.

7662-34, Session 8

Field calibration of reflective imagery of targets and backgrounds

V. A. Hodgkin, U.S. Army Night Vision & Electronic Sensors Directorate (United States); E. J. Boettcher, DCS Corp. (United States); D. D. Acton, Raytheon Co. (United States)

This paper describes a simple but powerful method for calibrating the apparent broadband flux reflectance of target and background materials in short wave infrared (SWIR) imagery in the field, a method that can also be used in other reflective bands. The method is analogous to the approach of field calibration of thermal infrared (TIR) imagery in which thermal references are positioned in a peripheral region of the sensor FOV to provide apparent temperature versus image grayscale. The principle difference between the emissive TIR approach and the reflective approach described here is that the references for the SWIR are passive and thus do not require active emission of in-band radiation. The simplest calibration approach provides apparent image reflectance versus image grayscale, but if image flux calibration is also desired, the use of a either a known in-band source to illuminate the references or a well characterized spectrophotometer to measure the ambient illumination can provide apparent flux versus image grayscale as well. All three variations were recently used in a field collection using a high quality, well characterized broadband SWIR imager, a low-power 1.523 um Helium Neon laser, and a recently calibrated spectrophotometer, and the results, theory, comparison with material database data, and error analysis are presented here.

7662-35, Session 8

Feasibility analysis and demonstration of high-speed digital imaging using micro-arrays of vertical cavity surface-emitting lasers

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Previous laser illumination systems at Aberdeen Proving Ground (APG) and elsewhere required complex pulse timing, extensive cooling, large-scale laser systems (frequency-doubled flash-pumped Nd:YAG, Cu-vapor, Q-switched ruby), making them difficult to implement for range test illumination in high speed videography. Requirements to illuminate through the self-luminosity of explosive events motivate the development of a high brightness imaging technique obviating the limitations of previous attempts. Vertical Cavity Surface-Emitting Laser (VCSEL) arrays and a lens system are proposed with temporal and spectral filtering to effectively remove self-luminosity and fireball from the image, providing excellent background discrimination in a range of range test scenarios.

Technical Imaging Division has immediate requirements for the development of a high speed photographic system to image objects engulfed in high radiance backgrounds, such as the self-luminosity associated with an explosion event. Use of laser illumination in conjunction with narrow band pass filtering and electro-optic shuttered temporal filtering provides background discrimination for high resolution, high speed digital image processing. In addition, the characteristics of the VCSEL structures now available represent viable lighting characteristics for other illumination events currently using flashbulbs and argon discharge lamps.

7662-36, Session 8

Display noise effects on target acquisition performance

S. D. Burks, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The presence of noise in an EO/IR imaging system adversely effects task performance in many cases. Typically when modeling the impact of noise upon task performance the focus is on noise generated at the front-end of the system (detector, amplifier, etc). However, there are cases when noise may arise in the back-end of the system due to different display technologies, etc. This paper presents a means to determine the effect of display noise on the sensor system noise under a variety of conditions. A perception study demonstrates that the effect of display noise correlates to the predicted modeled performance.

7662-37, Session 8

Visualizing the point spread function of a lens

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The point spread function (PSF) is an especially useful metric of lens performance. It can inform all sorts of decisions regarding optimal system specifications (e.g. FPA pixel size, image processing parameters, target acquisition capabilities, etc.). While theoretical PSF data is often calculable, its use is not widespread because of the difficulty involved with verifying experimental PSF performance. This paper provides details on a test system capable of visualizing a lens' PSF. In addition, preliminary methods of analyzing PSF performance are presented, including real-time visualization, encircled energy, and RMS spot size.

7662-38, Session 8

Pixel-wise advanced calibration method for infrared cameras

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Accurate radiometric calibration is a key feature of modern infrared cameras. Considering the newly available focal plane arrays (FPA) exhibiting very high spatial resolution, faster readout speed along tailored spectral bands, we developed a method to provide a dedicated calibration of every valid pixel. The novel approach includes many original elements. It first basically accounts for the spatial variations of the detector spectral responsivity across the FPA pixels. Next it enables to tackle spatial and temporal variations of the intrinsic charge accumulation mechanisms such as sensor self-emission and detector dark current. Finally the method succeeds to encompass the various effects contributing to bias the accumulated charge during detector integration, as well as electronic offsets. Real-time implementation of the algorithm for megapixel-FPAs and for data throughputs larger than 100 Mpixels/s shows promising performances.

7662-39, Session 8

Fast and precise point-spread function measurements of IR optics at extreme temperatures based on reversed imaging conditions

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Point Spread Function (PSF), Modulation Transfer Function (MTF) and Ensquared Energy (EE) are important performance indicators of optical systems for surveillance and target tracking applications. Beside fast real time adjustment and precise characterization under room temperature it is necessary to characterize the performance of an optical module under extreme temperature conditions during development and qualification.

We report on the development of a new measurement method which facilitates fast real time measurement of the 2D-PSF and related performance parameters of an IR optical module under room temperature as well as under extreme temperature conditions. Our new measurement setup uses the law of reversibility of optical paths to capture a highly resolved, magnified image of the PSF. By using of an easy add-on thermally insulating enclosure the optical module can be exposed to and measured under both variable high and low temperatures without any external impact on the measurement. Also bore sight and various off-axis measurements are possible.

Common PSF and MTF measurement methods (like scanning slit or edge methods or magnified projection of PSF) need much more correction algorithms, whilst our method requires mainly a pinhole diameter correction only and allows fast measurements of optical parameters under temperature. Additionally comparison of the captured, highly resolved PSF with optical design data enables purposeful theoretical investigation of occurring optical artefacts.

7662-46, Session 8

Non-optically combined multispectral source for IR, visible, and laser testing

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SBIR has developed a new, non-optically source for the testing of multi-spectral sensors. This source allows concurrent testing of IR, visible, and/or laser systems. The source has been designed to allow field testing of multi-spectral / fusion systems. We will present a description of the source along with performance data including output in pertinent spectral bands, stability and resolution. We will also present results demonstrating the use of the source for system testing including MRT, resolution, boresight and focus.

The new source is designed to support testing of emerging multi-spectral imagers and has been designed to be compact and rugged enough to allow field testing of sensors over a broad range of environments. The new source combines a blackbody and an integrating sphere with the option of adding a visible or laser source for simultaneous testing. The source allows independent and concurrent control of blackbody temperature, visible output and laser power.

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7663-01, Session 1

Two-band DMD-based infrared scene simulator

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OPTRA is developing a two-band midwave infrared (MWIR) scene simulator based on digital micromirror device (DMD) technology; this simulator is intended for training various IR tracking systems that exploit the relative intensities of two separate MWIR spectral bands. Our approach employs two DMDs, one for each spectral band, and an efficient optical design which overlays the scenes reflected by each through a common telecentric projector lens. Other key components are miniature thermal sources and a series of dichroic beamsplitters. Through the use of pulse width modulation, we are able to control the relative intensities of objects simulated by the two channels thereby enabling realistic scene simulations of various targets and projectiles approaching the tracking system. Performance projections support radiant intensity levels, resolution, bandwidth, and scene durations that meet the requirements for a host of IR tracking test scenarios.

In this paper we summarize the design and build and detail the system characterization of a prototype two-band simulator. System characterization results include maximum radiant intensity, radiant intensity resolution, angular resolution, and image registration. We also present a series of relevant simulated scenes.

7663-02, Session 1

Projection technologies for imaging sensor calibration, characterization, and HWIL testing at AEDC

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The characterization, calibration, and mission simulation testing of imaging sensors require continual involvement in the development and evaluation of radiometric projection technologies. Arnold Engineering Development Center (AEDC) uses these technologies to perform Hardware in the Loop (HWIL) testing with high-fidelity complex scene projection technologies that involve sophisticated radiometric source calibration systems to validate sensor mission performance. Testing with the NIST BXR and MDXR offer improved radiometric and temporal fidelity in this cold background environment. The development of hardware and test methodologies to accommodate wide field of view (WFOV), polarimetric, and multi/hyperspectral imaging systems is being pursued to support a variety of program needs such as space situational awareness (SSA). Test techniques for the acquisition of data needed for scene generation models (solar/lunar exclusion, radiation effects, etc.) are also sought. The extension of HWIL testing to the 7V Chamber requires the upgrade of the current satellite emulation scene generation system. This paper provides an overview of pertinent technologies being investigated and implemented at AEDC.

7663-03, Session 1

Apparent temperature calculation and performance analysis of mid-wave infrared light-emitting diodes for use in infrared scene projection

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Recent advancements in gallium antimonide light emitting diode (LED) arrays have opened the way for the development of LED based infrared scene projectors. Infrared LED array technology offers the opportunity for high frame rates, broad dynamic range and high apparent temperatures. Since LEDs are narrow-band devices, relative to blackbody emitters, performance of an LED based infrared scene projector will be highly dependent on how a particular sensor detects apparent temperature and how it is calculated. Because of this dependence, this manuscript will review the methods used to compute apparent temperature and use those methods to analyze the potential performance of an LED based infrared scene projectors. This analysis will include radiant power, electrical power, voltage and current. The paper will begin with an overview of current infrared scene projector technology and operation, followed by an overview of basic radiometric calculations and perceptions of apparent temperature. This will lead into an analysis of how infrared sensing systems detect apparent temperature. Once these concepts are understood, a performance model based on published gallium antimonide LED array performance data will be constructed and used in the performance analysis of an LED based infrared scene projector. Finally, the results of this performance model will be utilized to examine the possible advantages and technical challenges of an LED based infrared scene projector.

7663-04, Session 1

Recent advances in interconnect bonding for 3D integration of high-density area arrays

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The demand for more complex and multifunctional microsystems with enhanced performance characteristics for military applications is driving the electronics industry toward the use of best-of-breed materials and device technologies. Three-dimensional (3-D) integration provides a way to build complex microsystems through bonding and interconnection of individually optimized device layers without compromising system performance and fabrication yield. Bonding of device layers can be achieved through polymer bonding or metal-metal interconnect bonding with a number of metal-metal systems (e.g. Cu-Cu, Cu/Sn-Cu, etc.). RTI has been investigating and characterizing Cu-Cu and Cu/Sn-Cu processes for high density area array imaging applications, demonstrating high yield bonding between sub-15 μm pads on large area array configurations. This paper will review recent advances in the development of high yield, large area array metal-metal interconnects which enable 3-D integration of heterogeneous materials (e.g. MCT FPAs with silicon ROICs) and heterogeneous fabrication processes (e.g. resistive IR emitters or micro-bolometers with RIICs) for imaging and scene projector applications.

7663-05, Session 1

Long-wave infrared nonuniformity correction using a microbolometer camera

J. D. LaVeigne, K. Sparkman, G. Franks, M. Prewarski, Santa Barbara Infrared, Inc. (United States)

A new non-uniformity correction (NUC) software capability has been developed at Santa Barbara Infrared, Inc. based on the IRWindows4 software platform. This new software has been tested on an engineering grade MIRAGE-XL (1024x1024) resistive emitter array using a relatively inexpensive COTS long wave infrared microbolometer camera. While the signal to noise ratio of the camera limits the uniformity that can be achieved at ambient temperatures, testing has shown that this camera can successfully to NUC over moderate (350K) to high (425K) apparent temperature achieving non-uniformities on the order of 3%. An overview of the algorithms, software, hardware, test procedures and measured NUC results will be presented. Projected performance and limitations of the camera will be discussed.

7663-06, Session 1

Component-level testing updates for the infrared polarized scene-generator demonstrator

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Polarization signature information is becoming more useful as an added discriminant in a variety of signature analysis applications. However, there are few infrared scene projection systems that provide the capability to inject target simulation images with polarization content into a seeker, or other imaging sensor. In a previous paper we discussed experimental results for an infrared (IR) polarized scene generator (PSG) concept demonstrator. The concept demonstrator operated in ambient environmental conditions and displayed polarized scenes of resolved targets. The to-be-developed IR PSG demonstrator must be capable of testing sensor systems operating in cryogenic-vacuum (cryovac) environments. The IR PSG must also be able to accurately project scenes with unresolved polarized targets. As part of the development process, several potential PSG components are being tested in LN2 environments to verify functionality and changes in behavior at ambient, vacuum, and cryovac conditions. This paper presents test data for several of the components. Components tested were IR sources, windows, and motion control components. We also present test data for an imaging polarimeter being developed to validate the PSG.

7663-07, Session 1

Two-color IR LED array

N. C. Das, U.S. Army Research Lab. (United States); F. J. Towner, Maxion Technologies, Inc. (United States)

Recently, there has been great interest in using infrared light emitting diode (LEDs) devices as light sources for IR scene projection experiments. Type II Interband cascade electroluminescence in the 5-8 m spectral region from an LED structure was first reported by Yang et al [1]. Using a type II broken gap InAs/GaInSb quantum well (QW), Lin et al [2] demonstrated experimentally the first interband cascade (IC) laser. Recently, we have reported the operation of LED arrays in the 3-4 µm wavelength region [3] and the 8-9 µm regions [4] from two separate device structures. However many IR sensor testing scenarios require light sources with broad and independently controlled wavelength tunable operation. In this paper we report the design and operation characteristics of a two color IR LED array grown on a single GaSb substrate.

The IC LED structure was grown by molecular-beam epitaxy on an n-type GaSb substrate. After growing a 1.0 m p+ GaSb bottom contact layer, the LWIR IC LED structure was grown containing a 30 period active/injection region. Next, a 0.5 m p+ GaSb middle contact layer was grown followed by the MWIR IC LED structure containing a 15 period active/injection region. Finally a 1.4 m p+ GaSb top contact and grating formation layer was grown. Each active/injection period includes an asymmetric InAs/Ga1-xInxSb/InAs "W" quantum well preceded by an n-type digitally graded InAs/AlSb super lattice injector.

The LED fabrication process starts with reactive ion etching of a top grating consisting of circles of varying diameters and pitches. Regions of the middle and bottom contact layers are exposed and individual MWIR/LWIR LED mesas are isolated from other pixels in the array using a two mask photolithography process. Silicon nitride dielectric is deposited by PECVD and contact windows are opened in the dielectric on the bottom, middle and top contact layers. Ti/Au metal contacts are then deposited. The spectral emission curve for both MWIR and LWIR devices are shown in Figure 1. For the MWIR device the peak emission occurs at 3.8 m where as for LWIR device peak emission occurs close to 8 m. This two color device can be used for IR scene projection to evaluate the sensor operation in the HWIL facility.

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7663-08, Session 1

Photonic crystal scene projector development

J. T. Caulfield, Cyan Systems (United States)

Cyan Systems is developing a new Extremely High Temperature Projector System Technology (XTEMPS). The XTEMPS is a multispectral emitter array based upon Photonic Crystals, providing high radiance and tailored spectral emission. Cyan has teamed with a state of the art MEMS fabrication facility, Sandia National Laboratory, to develop Tungsten based metallic Photonics Crystals (PhC) designed for Scene Projection systems. Photonic Crystals demonstrate improved output power efficiency when compared to broad band "graybody" emitters due to limiting the emission to narrow bands and recycling of energy from other bands into the "tailored" allowable bands. Not only do PhC based emitter pixels have a higher effective temperature output, but since the PhC has a large "forbidden" optical band, most of the input power is converted to the desired narrowband emission. Cyan has designed and demonstrated read-in integrated circuit (RIIC) compatible pixel designs with RIIC from Nova Sensors. We have demonstrated pixel structures for high radiative efficiency of the Photonic lattice, while suppressing undesired IR sidelobes. Cyan will provide XTEMPS Systems performance metrics and illustrate operating test structures. Cyan will discuss the theory and system design of Photonic Crystal based projection technology. We will also demonstrate the expected spectral tunability and power efficiency of Photonic Crystal based projection systems.

7663-09, Session 1

Large format resistive array scene simulation validation testing and readiness

J. Oleson, Oleson Convergent Solutions (United States)

Accurate simulation of InfraRed signatures has become a key need in the IR Scene Projection (IRSP) community. Radiometric accuracy of target signatures in both terrestrial and airborne environments is critical to mission success. NAVAIR Patuxent River has performed validation testing of their Large Format Resistive Array (LFRA) IRSP in support of top level IR system test and integration needs. The validation effort has been guided by the Navy Air Defense Threat Simulation Procedures Manual and supports JDIGS and other high priority programs. This paper discusses the validation process, IR scene projection measurements in support of it, and the planned use of the system in the coming months.

The validation process includes characterization of the LFRA system's radiometric accuracy versus known input. It also characterizes the spatial and temporal accuracy of the system when projecting dynamic imagery. Data from these test runs will be presented. Additional data, representing operational scenes will be collected. The key aspects of the scenes and the LFRA system's rendition of them will be compared to demonstrate the system's overall accuracy and repeatability.

7663-10, Session 1

256 x 256 GaSb-based type-I mid-IR LED addressable array for mid-IR scene projection

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LEDs and LED arrays operating at room temperature and emitting with wavelengths from 3 to 4.2 microns have been developed. Increasing the indium content of the InGaAsSb quantum wells decreases the band gap and increases the emission wavelength. Unfortunately, increasing the indium content also requires increasing the arsenic concentration to maintain reasonable lattice matching to the GaSb substrate. The result is a decrease in hole confinement for longer wavelength InGaAsSb alloys when used with traditional AlGaAsSb barriers. We have adopted a quinternary InAlGaAsSb barrier alloy that preserves effective hole confinement with InGaAsSb quantum wells emitting at up to 4.2 microns. These new devices exhibit improved LED efficiency and output power.

Large scale arrays of independently addressed LEDs of up to 256x256 have been produced. These arrays exhibit good uniformity due to high quality molecular beam epitaxial growth. Larger arrays are technically feasible.

Spectrum tailoring using multiple quantum wells of differing design is discussed. These devices allow the production of LEDs with broad spectra which can be matched to the application's requirements.

Devices that can emit two colors simultaneously have been fabricated. These devices utilize two distinct LED active regions that share a common contact layer. The current, and thus the emission intensity, of each active region can be independently controlled for real time modification of the emission spectra. Arrays of these bicolor LEDs with independent control of the color intensity of each pixel open the way for effective multispectral scene projection.

7663-11, Session 1

Interband cascade resonant cavity emitters and vertical cavity surface emitting lasers for 2D-array scene projectors

J. L. Bradshaw, J. D. Bruno, K. M. Lascola, Maxion Technologies, Inc. (United States); G. P. Meissner, U.S. Army Research Lab. (United States); J. T. Pham, F. J. Towner, Maxion Technologies, Inc. (United States)

The development of a 2D-architecture for MWIR and LWIR quantum emitters would be a great benefit for HWIL applications such as IR scene projectors and LADAR scene generation and projection. This is particularly true in the MWIR range were the incumbent technology, resistive silicon arrays, is inherently inefficient because these arrays generate heat, not light. Also, the simulation of fast dynamic thermal scenes by resistive silicon arrays is limited by the thermal time constant of the individual pixels. Because quantum emitters are inherently fast devices with electrical response times in the nanosecond to sub-nanosecond range, 2D arrays of such emitters can simulate very fast dynamic scenes - provided the quantum efficiency for light generation is high enough.

Maxion Technologies has been developing Interband Cascade LED arrays for infrared scene generation applications. Currently, the small pixel sizes mandated by the array pitch requirements are limiting demonstrated output powers and therefore the achievable effective blackbody temperatures to the 800-900 Kelvin range. One approach toward overcoming this problem is to improve the light extraction efficiency in the LEDs. Another approach is to bypass LEDs entirely and create vertical cavity surface emitting laser (VCSEL) arrays. This talk will describe Maxion's progress toward the development of a mid-IR Interband Cascade VCSEL array for mid-IR scene generation. We will describe the design, growth, fabrication and testing of several vertical-cavity structures and assess the likelihood of the demonstration of an interband cascade LED structure in the near future.

7663-12, Session 2

Distributed and ground-based IRCM testing

D. Greer, Naval Air Warfare Ctr. Aircraft Div. (United States)

Infrared Countermeasures (IRCM) testing has historically been dominated by live fire testing. While live fire testing will always be a vital part of IRCM Test and Evaluation (T&E), next generation technological developments are hoped to enable closed-loop ground-based IRCM testing to provide valuable complementary test data. High cost and limited assets prevent live fire data from providing a thorough data set required for T&E analysis. Ground-based testing aims to execute thousands of simulation and stimulation scenarios in an effort to completely evaluate an IRCM suite prior to live fire validation testing. End-to-end testing includes missile launch, Missile Warning System (MWS) detection, Countermeasure (CM) hand-off, CM dispense/jam, and break-lock/miss distance calculation. Parts of the end-to-end testing have been successfully completed in ground test such as MWS stimulation and break-lock measurements. A new Central Test and Evaluation Investment Program (CTEIP) funded team is upgrading the capabilities at multiple Department of Defense (DoD) test facilities that will enable full end-to-end testing. The goal is to provide this closed-loop capability in a ground test environment in order to provide decision quality data to research, development and acquisition customers. The challenge is combining the capabilities of various laboratories around the United States into a single test capability. If a MWS stimulation can be completed in one lab and a Hardware-In-The-Loop (HITL) lab can compute missile miss distance, how can the two labs work together to provide both capabilities simultaneously?

7663-13, Session 2

Missile Airframe Simulation Testbed (MAST): HWIL in the Sky

J. Clements, U.S. Army AMRDEC (United States); J. Robinson, R. M. Robinson, P. M. Roberts, The AEgis Technologies Group, Inc. (United States)

Surface-to-air missile development programs typically utilize a hardware-in-the-loop (HWIL) simulation to provide a non-destructive high volume test environment for what are typically very expensive guidance sections. The HWIL, while invaluable, has not been able to obviate the need for missile flight tests. Because of the great expense of these missiles, the designers only get to perform a fraction of the tests desired. MAST is a program conceived by US Army Missile and Aviation RDEC that blends the non-destructive nature of HWIL with the confidence gained from flight tests to expand the knowledge gained while reducing the development schedule of new programs. In addition, other uses have been identified that take advantage of this new capability for war fighting exercises and the development and testing of aircraft countermeasure systems.

7663-14, Session 2

The synergistic roles of test and hardware-in-the-loop simulation in the life cycle of the Army Tactical Missile System

D. M. Curry, G. W. Ricks, U.S. Army Aviation and Missile Command (United States)

The Army Tactical Missile System (ATACMS) has been fielded with the US Army for almost 20 years as a deep strike precision weapon, capable of engaging time critical targets at high precision under all weather conditions. Over its long lifespan, the ATACMS system has undergone numerous upgrades to improve system accuracy, extend the missile's range capabilities, and evolve the missile's warhead to keep up with its changing role for the soldiers in the field. Throughout this long history, the Hardware-in-the-Loop (HWIL) Simulation at the Army Aviation and Missile Research, Development, and Engineering Center has played a major role in the development, maintenance, and testing of the missile. This paper will describe the use of the HWIL simulation in the design of the missile, validation of the simulation, the role of the simulation in the production and test process, how the simulation is used to support system shelf life and obsolescence issues and how the simulation is used to answer critical user questions on the performance of the system.

7663-15, Session 2

Rapid common hardware-in-the-loop development

H. J. Kim, U.S. Army AMRDEC (United States); S. Moss, The AEgis Technologies Group, Inc. (United States)

An approach to streamline the Hardware-In-the-Loop (HWIL) simulation development process is under evaluation. With increased microprocessor speed, FPGA capacity and increased bus bandwidth over the last decade, a common interface design may be able to support a large number of HWIL interfaces that were previously custom designed interfaces. The Common HWIL approach will attempt to provide a more flexible, scalable system. The overall goal of the Common HWIL system will be to reduce cost by minimizing redundant development and operational labor and equipment expenses. This paper will present current results and future plans of the development.

The U.S. Army Research, Development and Engineering Command (RDECOM) Aviation and Missile Research, Development and Engineering Center (AMRDEC) is pursuing the establishment of a Common HWIL interface as well as a rapid prototype laboratory based on the resulting standard. The system is planned to employ a standardized overall architecture as well as consistent component design to allow faster development and integration during facility buildup. It is also being developed to utilize reusable modules designed for adaptation to specific test articles.

The overarching architecture will be scalable to accommodate stand-alone, bench top experiments of a single test article, or a composition of multiple, geographically dispersed test articles spanning numerous weapon systems. Test articles may be hardware only, processor-in-the-loop, or all-digital representations. This will permit Common HWIL to integrate hardware items from various technologies in any combination desired. Multiple Common HWIL laboratories may also be linked via suitable protocol as another technique for achieving force-on-force level simulations. With the standard interfaces and an external synchronization concept, the common HWIL approach will provide a capability that assures validity and repeatability of real-time simulation results.

7663-16, Session 3

Major discriminators in the facility design of infrared flight motion simulators

R. W. Mitchell, Ideal Aerosmith, Inc. (United States)

Target Scene Projectors (TSP) mounted to a Flight Motion Simulator (FMS) require a high degree of gimbal stability to prevent image blur. Seeker systems require a stable target scene to follow a kinetic impact scenario. The facility design must account for the FMS motion dynamics with a stable pier and floor anchoring system. The facility power must be sufficient to provide maximum accelerations and rates either continuously or with a specified duty cycle. A tradeoff exists between travel dynamics and facility power. High gimbal dynamics require power in proportion to the gimbal accelerations and rates. High dynamics also require a substantial pier design to maintain pointing accuracies throughout the system-operating envelope. This allows higher accuracy seekers to remain on target during the highly dynamic terminal phase of a mission scenario.

Tradeoff curves are presented between FMS dynamics, facility power, and physical size. With the major discriminators determined, relationships are provided for the other facility parameters as environmental specifications and cooling requirements.

A typical facility plan is generated that can be used as a template for an Interface Control Document (ICD) to ensure the FMS and the facility have a smooth installation and provide a safe operating environment.

7663-17, Session 3

Weighted least-mean-squares based control for a four-axis gimbal set

D. R. Carter, P. Duffey, M. Kägi, H. S. Havlicsek, S. J. Bachorski, Acutronic USA, Inc. (United States)

Gimbal lock is a phenomenon which occurs in multi-gimbaled systems when two axes are driven into a coplanar orientation, thereby resulting in the loss of one degree of rotational freedom. This paper presents a control scheme which introduces a redundant fourth axis in conjunction with an algorithm that minimizes weighted least-mean-square gimbal rates, ultimately permitting the use of open inner and middle gimbals to achieve a wide field of view. The control algorithm produces a singularity/gimbal lock measure which is derived using the inner three gimbals, and used to adapt the weights and transition the table from three-axis operation to four-axis operation at or near the three-axis gimbal lock orientation. Weight adaptation minimizes the peak gimbal rate required to track a vehicle reference rate profile. The control strategy also minimizes tracking errors between vehicle kinematic motion, which is obtained from the vehicle dynamics simulation, and kinematic motion induced onto the table-mounted payload. The control algorithm accepts Euler angles and body rates, as defined in the body fixed frame of reference, and generates four gimbal command sets. Each gimbal command

set consists of gimbal acceleration, rate, and angle. Mathematical analysis, simulation, and 3-D CAD multi-body dynamics visualizations are included, illustrating differences between desired vehicle kinematic motion and that induced by this control strategy onto the table mounted payload, including an examination of effects due to finite gimbal control loop bandwidths.

7663-18, Session 4

Infrared transfer radiometer for broadband and spectral calibration of space chambers

T. M. Jung, Jung Research and Development Corp. (United States); A. C. Carter, Booz Allen Hamilton (United States); S. I. Woods, S. G. Kaplan, R. U. Datla, National Institute of Standards and Technology (United States)

The Low-Background Infrared (LBIR) facility at NIST has recently completed construction of an infrared transfer radiometer with an integrated cryogenic Fourier transform spectrometer (Cryo-FTS). This mobile system can be deployed to customer sites for broadband and spectral calibrations of space chambers and low-background HWIL testbeds. The Missile Defense Transfer Radiometer (MDXR) has many of the capabilities of a complete IR calibration facility and will replace our existing filter-based transfer radiometer (BXR) as the NIST standard detector deployed to MDA facilities. The MDXR features numerous improvements over the BXR, including: a cryogenic Fourier transform spectrometer, an on-board absolute cryogenic radiometer (ACR), an internal blackbody reference, and an integrated collimator. The Cryo-FTS can be used to measure high resolution spectra from 4 to 20 micrometers, using a calibrated Si:As blocked-impurity-band (BIB) detector. The on-board ACR can be used for self-calibration of the MDXR BIB as well as for absolute measurements of infrared sources. A set of filter wheels and a rotating polarizer within the MDXR allow for filter-based and polarization-sensitive measurements. The optical design of the MDXR makes both radiance and irradiance measurements possible and enables calibration of both divergent and collimated sources. Details of the various MDXR components will be presented as well as initial testing data on their performance.

7663-19, Session 4

MMW target and clutter characterization using the range instrumentation synthetic aperture radar

J. A. Ray, U.S. Army AMRDEC (United States)

The U.S. Army Research, Development and Engineering Command (AMRDEC) and Redstone Test Center (RTC) at Redstone Arsenal, Alabama have developed a Ka band, range instrumentation synthetic aperture radar (RISAR) for the purpose of millimeter wave (MMW) target and scene characterization. RISAR was developed as one element of the Advanced Multi-Spectral Sensor and Subsystem Test Capabilities (AMSSTC) program funded and managed by the U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI), Project Manager for Instrumentation, Targets and Threat Simulators (PM ITTS). The key objective of RISAR is the collection of MMW SAR data that can be used to develop high resolution target and terrain models for use in digital and real-time hardware-in-the-loop simulations.

The purpose of this presentation is to provide an overview of RISAR development and implementation. Example results of funded data collections will be presented with an emphasis on the system's 3D target modeling capabilities for ground targets, and wake characterization capabilities for littoral targets.

7663-20, Session 4

Fast methods for computing scene raw signals in millimeter-wave sensor simulations

R. F. Olson, U.S. Army AMRDEC (United States); T. M. Reynolds, H. D. Satterfield, Simulation Technologies, Inc. (United States)

Modern millimeter wave (mmW) radar sensor systems employ wideband transmit waveforms and efficient receiver signal processing methods for resolving accurate measurements of targets embedded in complex backgrounds. Fast Fourier Transform processing of pulse return signal samples is used to resolve range and Doppler locations, and amplitudes of scattered RF energy. Angle glint from RF scattering centers can be measured by performing monopulse arithmetic on signals resolved in both delta and sum antenna channels. Environment simulations for these sensors - including all-digital and hardware-in-the-loop (HWIL) scene generators - require fast, efficient methods for computing radar receiver input signals to support accurate simulations with acceptable execution time and computer cost. Although all-digital and HWIL simulations differ in their representations of the radar sensor (which is itself a simulation in the all-digital case), the signal computations for mmW scene modeling are closely related for both types. Engineers at the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) have developed various fast methods for computing mmW scene raw signals to support both HWIL scene projection and all-digital receiver model input signal synthesis. These methods range from high level methods of decomposing radar scenes for accurate application of spatially-dependent non-linear scatterer phase history, to low-level methods of efficiently computing individual scatterer complex signals and single precision transcendental functions. The efficiencies of these computations are intimately tied to math and memory resources provided by computer architectures. The paper concludes with a summary of radar scene computing performance on available computer architectures, and an estimate of future growth potential for this computational performance.

7663-21, Session 5

Real-time maritime scene simulation

E. T. Gouthas, C. L. Christie, L. Swierkowski, O. M. Williams, Defence Science and Technology Organisation (Australia)

The real-time simulation of maritime scenes of tactical interest is complex, in terms of both the interactions between the phenomena that need to be addressed and the balance required in order to sustain real-time performance without unnecessarily compromising on the accuracy of the effects being simulated. The effects include the simulation of ocean surfaces in different sea states, the physically-realistic representation of boat and ship dynamics, wake generation and generation of surface effects including whitecaps, spray, wake trails and foam.

In this paper we describe recent improvements in our maritime scene generation program and the extension in capabilities that has been achieved. The motion of multiple boats under independent control can now be simulated, as well as large ship motion. Our approach to the resulting complexities has been to develop a number of graphical user interface tools that control the parameters associated with the disparate phenomena being simulated, allowing the latter to be configured separately and later tuned within the integrated maritime environment. We describe the tools, the underlying phenomena that they control and their application in enabling versatile real-time maritime scene simulation.

7663-22, Session 5

Real-time scene generation infrared radiometry

O. M. Williams, C. L. Christie, G. Shen, E. T. Gouthas, L. Swierkowski, Defence Science and Technology Organisation (Australia)

The continuing advancement in processing power available in standard PC-based graphics cards has enabled quite complex scenes to be rendered in real-time, suitable for the hardware-in-the-loop simulation of imaging infrared units-under-test. Requirements now include not only the targets of interest and their emissions, but also land, sea and sky backgrounds, and transmission and reflection effects, all rendered on a per-pixel basis.

For simulation validity, every attempt needs to be made to replicate the scene radiance occurring in real-world operation, particularly in conditions where trials data for validation purposes may be sparse or unavailable. In this paper we describe our infrared scene generation approach from the radiometric perspective. This approach involves the application of a number of techniques that together enable real-time operation to be sustained: storage of offline MODTRAN-generated data, pre-runtime in-band Planck law calculations, use of a Fresnel law approximation for water reflection, use of cubemaps for background contributions, bidirectional reflectance distribution function (BRDF) approximation for emulating different surface types, amongst others. We describe each of these techniques and include examples of real-time scenery generated for our aircraft and small boat simulations of current interest, with special comments on their hardware-in-the-loop simulation applicability and validation aspects.

7663-24, Session 5

GPU-based synthetic scene generation for maritime environments

W. A. Keen, SYColeman Corp. (United States); M. A. Tanner, Air Force Research Lab. (United States)

Hardware and software in the loop modeling of maritime environments involves a wide variety of complex physical and optical phenomenology and effects. The scale of significant effects to be modeled range from the order of centimeters for capillary type waves and turbulent wake effects up to many meters for rolling waves. In addition, wakes for boats and ships operating at a wide variety of speeds and conditions provide additional levels of scene complexity. Generating synthetic scenes for such a detailed, multi-scaled and dynamic environment in a physically realistic yet computationally tractable fashion represents a significant challenge for scene generation tools. In this paper, next generation scene generation codes utilizing PC graphics processors with programmable shaders as well as Cuda and OpenCL implementations will be presented. Characterization of throughput performance as well as estimates of scene accuracy will be provided.

7663-25, Session 5

Exploiting current-generation graphics hardware for synthetic-scene generation

M. A. Tanner, Air Force Research Lab. (United States); W. A. Keen, SYColeman Corp. (United States)

Increasing seeker frame rates and pixel counts, as well as the demand for higher levels of scene fidelity have been driven scene generation software for HWIL and SWIL testing to higher levels of parallelization in recent years. Because modern PC graphics card provide the potential multiple computational cores (240 shader cores for a current NVIDIA GeForce and Quadro cards), implementation of phenomenological codes on GPU offers significant potential for simultaneous enhancement of simulation frame rates and fidelity. To take advantage of this potential requires algorithms and implementation be structured in such a way as to minimize data transfers between the CPU and the GPU. In this paper, some preliminary methodologies developed at KHILS will be presented. Included in this presentation will be various language trades between conventional shader programming, CUDA and OpenCL, including performance trades and pathways for tool development going forward. In addition, some techniques for program structure which takes maximum advantage of GPU processing power while minimizing data transfers will be presented.

7663-26, Session 5

Temporally and spatially resolved scene generation for semi-active laser sensing systems

J. E. Burns, Torch Technologies, Inc. (United States); G. A. Wiggs, U.S. Army AMRDEC (United States); T. Fronckowiak, Jr., M. O'Melia, Torch Technologies, Inc. (United States)

The U.S. Army AMRDEC System Simulation and Development Directorate has developed the Common Scene Generator (CSG) to support the multi-spectral scene generation and high-fidelity simulation requirements for tactical IR, MMW, SAL and multi-mode missile systems. The SAL scene generation components represents a unique scene generation approach which calculates and presents the the seeker dome time resolvable irradiance at the seeker dome, based on a 3-D projection of designator energy onto a faceted scene, projected into the seeker frame of reference. The CSG models the emitted pulse from the designator including optics geometry, dispersion and atmospheric turbulence, incorporating designator platform jitter. The energy is projected through an atmospheric model which includes transmission loss and scatter. The SAL SG solution in CSG fully handles shadowing between all components in the scene and presents effects such as spill and scatter to the sensor. CSG implements countermeasure models such as smoke which may affect SAL tracker performance. This paper provides an overview of the implementation, verification, and describes a typical use scenario for this tool. This presentation will also demonstrate how the SAL SG component might be integrated with a quad-cell SAL sensor model for integration into a processor in the loop type environment.

7663-27, Session 5

A real-time unified scene-generation framework for hardware-in-the-loop simulation

D. H. Bunfield, The AEgis Technologies Group, Inc. (United States); D. E. Trimble, Davidson Technologies, Inc. (United States); J. Davis, Torch Technologies LLC (United States); J. W. Morris, G. H. Ballard, U.S. Army AMRDEC (United States)

AMRDEC sought out an improved framework for real-time hardware-in-the-loop (HWIL) scene generation to provide the flexibility needed to adapt to rapidly changing hardware advancements and provide the ability to seamlessly integrate external third party scene generation codes. As such, AMRDEC has developed ContinuumCore, a new architecture to allow for the integration of these codes into a HWIL lab facility while maintaining compatibility with existing HWIL scene generation codes such as the Joint Signature Image Generator (JSIG). This new real-time framework is a minimalistic modular approach based on the National Institute of Standards (NIST) Neutral Messaging Language (NML) that provides the basis for common HWIL scene generation. This minimalistic approach leverages heavily on design pattern-based coding techniques and allows the scene graph, scene, and associated phenomenology to be designed around the data. Because of this open architecture approach, the framework also facilitates load distribution across multiple high

performance platforms to take advantage of the latest advancements in GPU hardware, such as NVIDIA's Tesla and Fermi architectures, providing an increased benefit in fidelity and performance of the associated scene's phenomenology. Other features of the ContinuumCore easily extend the use of this framework to include visualization, diagnostic, analysis, and other HWIL and all digital simulation tools.

7663-28, Session 5

Record breaking high-apparent temperature capability of LCoS-based infrared scene projectors

J. R. Lippert, Kent Optronics, Inc. (United States)

A newly fabricated Infrared Scene Projector (IRSP) configured for the Long Wave IR regime has demonstrated simulated apparent temperatures exceeding 1500 K, more than doubling the maximum temperature capability of prior pixilated scene projector devices. Since the entire array surface is capable of this high temperature output, the same device can be used to generate both the moderate temperature scene background and an unlimited number of high temperature targets in the scene, without having to optically combine a few discrete "hot spot" generators. This performance was enabled by advances in a new large pixel, high voltage, 16-bit backplane Spatial Light Modulator coupled with an intense spectral illumination source, and special formulation liquid crystal. The new LC formulation and SLM configuration also achieves an effective usable frame rate of up to 200Hz capability. Performance characterization and results will be discussed, and data presented in the paper.

This effort was accomplished in a Phase 2 SBIR sponsored by the Missile Defense Agency (MDA).

Conference 7664: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XV

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Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XV

7664-01, Session 1

Detection of multiple unexploded ordnance using the TEMTADS and MPV sensors

T. M. Grzegorczyk, Delpsi, LLC (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); F. Shubitidze, J. P. Fernández, I. Shamatava, Dartmouth College (United States); K. A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States)

We report the simultaneous detection of multiple unexploded ordnance (UXO) using Electromagnetic Induction (EMI) data collected with the Man Portable Vector (MPV) sensor and the TEMTADS sensor array. In both cases, the positions and electromagnetic signatures of the targets are unknown and are inverted for. This task is performed using a regularized Gauss-Newton method combined with the dipole model. The sharp spatial falloff of the magnetic field in the EMI regime justifies the use of the dipole model in situations where the targets are not very close to the sensor, or are not heterogeneous. In addition, the dipole model allows the analytical computation of the Jacobian matrix and therefore contributes to the speed efficiency of the algorithm.

In the MPV case, results are shown for one and two targets in proximity, and the ability to perform a reliable detection and classification is studied as function of receiver number and position. In the TEMTADS case, we use the 25 transmitters and 25 receivers alternatively in a monostatic and a bistatic configuration (using all 625 data points). It is shown that both operation modes are effective at inverting for the position and polarizability of single targets, but that the bistatic configuration is superior for the detection and classification of multiple targets. Results for two and three targets are discussed and classification is quantified as function of inter-target separation. It is shown that three UXO can be properly classified if they are about one characteristic distance away from each other.

7664-02, Session 1

Combining electromagnetic induction and automated classification in a UXO discrimination blind test

J. P. Fernández, F. Shubitidze, I. Shamatava, Dartmouth College (United States); B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States)

The Strategic Environmental Research and Development Program (SERDP) is administering benchmark blind tests of increasing realism to the UXO community. One of the latest took place at the Aberdeen Proving Ground in Maryland: 214 cells, each one containing at most one buried target, were interrogated with the TEMTADS electromagnetic induction (EMI) sensor array. Each item could be one of six standard ordnance or could be harmless clutter such as shrapnel. The test called for singling out potentially dangerous items and classifying them. Our group divided the task into three steps: location, characterization, and classification. For the first step the HAP method was used. The method assumes a pure dipolar response from the target and finds the position and orientation using the measured field and its associated scalar potential, the latter computed using a layer of equivalent sources. For target characterization we used the NSMS model, which employs an ensemble of dipole sources arranged on a spheroidal surface. The strengths of these sources are normalized by the primary field that strikes them; their surface integral is an electromagnetic signature that can be used as a classifier. In this work we look into automating the classification step using a multi-category support vector machine (SVM). The algorithm

runs binary SVMs for every combination of pairs of target candidates, apportions votes to the winners, and assigns unknown examples to the category with the most votes. We look for the feature combinations and SVM parameters that result in the most expedient and accurate classification.

7664-03, Session 1

SLO blind data set inversion and classification using physically complete models

I. Shamatava, F. Shubitidze, Sky Research, Inc. (United States); J. P. Fernández, Dartmouth College (United States); B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States); T. M. Grzegorczyk, Delpsi, LLC (United States)

The main objective of this paper is to demonstrate the EMI data inversion and classification performance of the Parameterized Normalized Surface Magnetic Source (PNSMS) model. The PNSMS is combined with differential evolution optimization and with the HAP method to invert for the locations and orientations of the targets of interest. The model provides at least three independent parameters that can be used for discrimination. During the inversion stage the total PNSMS is determined as a function of time for each blind data cell. Here we present discrimination studies carried out on 1464 data sets collected by the TEMTADS sensor at the SLO UXO site. The sets included four types of UXO: 2.36" rockets and 60-mm, 81-mm and 4.2-inch mortars. For each target the total PNSMS amplitudes along three orthogonal axes were inverted from calibration data and then used to extract the Pasion-Oldenburg parameters. These in turn were used to discriminate UXO from metallic clutter and to classify the different UXO. We inverted the data to determine the PNSMS strengths for each cell and used the obtained time-decay curves to extract the discrimination features and perform classification using the previous data as reference. We examined the entire time decay history of the total PNSMS case-by-case for classification purposes. Also, we use different multi class statistical classification algorithms to separate dangerous objects from non hazardous items. In addition, for cross-validation purposes, the inverted locations and orientations from PNSMS -DE algorithm were compared against inverted data obtained via the HAP method.algorithms to separate dangerous objects from non hazardous items. In addition, for cross-validation purposes, the inverted locations and orientations from PNSMS -DE algorithm were compared against inverted data obtained via the HAP method.

7664-04, Session 1

Transient electromagnetic responses during the transmitter on-time

G. M. Schultz, J. S. Miller, L. Pasion, Sky Research, Inc. (United States)

Current time-domain electromagnetic induction instruments generally only utilize data acquired after the cessation of the transmitted field. During this "off time" signals are dominated by induced eddy currents and magnetic surface modes, but do not fully capture the magnetostatic response of permeable and conductive metallic ordnance. In this paper, we investigate the response of EMI systems that measure signals during excitation of the primary magnetic field (the so-called "on-time"). Our analysis shows that on-time signals have great potential to yield useful information that is not often exploited in current EMI systems. We compare analytical models to data from state-of-the-art time-domain

EM sensors that have the capability to sample receivers during the on-time. We present modeling results that represent the responses from different current ramps and on-time waveforms for objects and ground. We consider target and clutter objects and grounds having a range of material properties, shapes and sizes, and configurations and investigate signal processing and inversion methods for target detection and discrimination. Specifically, correlations between on-time and off-time signals are shown to be a powerful tool for discriminating ferrous and non-ferrous metallic objects.

7664-05, Session 1

Target localization techniques for vehicle-based electromagnetic induction array applications

J. S. Miller, G. M. Schultz, F. Shubitidze, Sky Research, Inc. (United States)

State-of-the-art electromagnetic induction (EMI) arrays provide significant capability enhancement to landmine, unexploded ordnance (UXO), and buried explosives detection applications. Specifically, arrays that are easily and quickly configured for integration with a variety of ground vehicles and mobile platforms offer improved safety and efficiency to personnel conducting detection operations including route clearance, explosive ordnance disposal, and humanitarian demining missions. Currently, most EMI sensors measure a set of magnetic field parameters such as vector field components or gradient tensor elements that are typically used for real-time threat detection based on threshold analysis. Techniques that further exploit EMI data in real-time to extract target features including target location and polarizability may significantly reduce false alarms generated during basic threshold-level detection. We present results from an evaluation of an advanced ground vehicle-based EMI array. Our research includes implementation of numerical techniques to estimate target depth and location from sensor overpass measurements of the vertical magnetic field component scattered by a buried target. These techniques can be adapted to any EMI array configuration, and thus offer the potential for widespread application.

7664-06, Session 1

Applying a volume dipole distribution model to next-generation sensors data for multi-object data inversion and discrimination

F. Shubitidze, J. P. Fernández, Dartmouth College (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); I. Shamatava, Sky Research, Inc. (United States); K. A. O'Neill, Dartmouth College (United States); T. M. Grzegorczyk, Delpsi, LLC (United States); A. Bijamov, Dartmouth College (United States)

Discrimination between UXO and harmless objects is particularly difficult in highly contaminated sites where two or more objects are simultaneously present in the field of view of the sensor and produce overlapping signals. The first step in overcoming this problem is estimating the number of targets. In this work a dipole volume distribution model is utilized for estimating the number of targets, along with their locations and orientations. The technique is based on the discrete dipole approximation, which distributes dipoles inside the computational volume. The dipole moment density distribution is represented with an empirical distribution function. The function has multiple poles. Each pole corresponds to a Scattered Field Singularity (SFS) (corresponding to a dipole source). For multiple-target scenarios there are multiple SFS locations, so the distribution function has several poles distributed inside the computational volume. The measured field depends linearly on the amplitudes of the dipoles, which can therefore be determined by fitting measured and modeled data. The field produced by the volume distributed dipoles with unit amplitudes are recomputed for a fixed

sensor location and are used to determine the number of poles of the distribution function, as well as their locations, via iterative techniques or the Markov chain Monte Carlo method. The algorithm is tested with full vector TD MPV data sets collected at the Hanover office of Sky Research and with bi-static TEMTADS multitarget data sets. The performance of the method with regard to computational speed and discrimination ability are reported

7664-07, Session 1

Comparison of the physically complete model with a simple dipole model for UXO detection and discrimination

F. Shubitidze, J. P. Fernández, Dartmouth College (United States); I. Shamatava, Sky Research, Inc. (United States); B. E. Barrowes, K. A. O'Neill, U.S. Army Engineer Research and Development Ctr. (United States); T. M. Grzegorczyk, Delpsi, LLC (United States)

In this paper we apply the physically complete normalized surface magnetic source (NSMS) model and a variant of the simple dipole model to invert electromagnetic induction (EMI) data collected by new-generation digital geophysical instruments over subsurface highly conducting and permeable metallic scatterers. Such investigations are of particular value for the unexploded ordnance discrimination problem. The discrimination process concerns two sets of parameters: intrinsic parameters associated to a target's size, shape and material composition and extrinsic parameters related to the orientation and location of the anomaly. To discriminate UXO from clutter, first a mathematical model is fit to the geophysical data and both intrinsic and extrinsic parameters are extracted using optimization techniques; the inverted intrinsic parameters are used for isolating objects of interest from non hazardous items. Thus the discrimination performance depends significantly on the mathematical model. In this work we present results of applying the single dipole, multi dipole and NSMS models to scalar and vector data from new-generation EMI instruments such as the MPV and the Metal Mapper, both of which are time domain systems. The MPV has a single transmitter and five tri-axial receivers, while the Metal Mapper is a cart-based system with three rectangular transmitters and five tri-axial receivers distributed on a plane. Both instruments produce high quality, well located EMI data. We assess the inversion and discrimination performance of the three forward models by applying them to the data. Specifically, we present comparisons between the inverted intrinsic and extrinsic parameters determined from each model and the actual true values.

7664-08, Session 1

Source separation using sparse-solution linear solvers

J. T. Miller, D. A. Keiswetter, J. B. Kingdon, T. Furuya, B. J. Barrow, T. H. Bell, SAIC (United States)

A new algorithm is proposed to locate and characterize individual signal sources, given observation of their combined signals. We assume a forward model is available, that it represents a smooth mapping between source parameters and associated signals, and that superposition holds: coupling between sources is ignored. The algorithm proceeds iteratively by solving the matrix equation y=Ax where columns of A contain normalized expected signals from a collection of hypothesized sources, and the column vector y contains the combined signal measurement. Recently developed solvers which provide sparse non-negative solutions and fast computation times make this approach feasible even when large numbers of hypothesized sources are involved. With each iteration, the collection of hypothesized sources is refined, based on the recent record of weights x assigned by the solver. Application is demonstrated on the problem of locating multiple buried conductors based on electromagnetic induction (EMI) signals observed at ground surface.

7664-09, Session 1

Adapting physically complete models to vehicle-based EMI array sensor data: data inversion and discrimination studies

F. Shubitidze, Dartmouth College (United States); J. S. Miller, G. M. Schultz, Sky Research, Inc. (United States); J. A. Marble, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

In this paper, physically complete models such as the normalized surface magnetic source (NSMS), multi-dipole, and volume distributed dipole models are applied to state-of-the-art electromagnetic induction (EMI) array data. Such investigations are particularly useful for improving the detection and discrimination of subsurface targets such as unexploded ordnance, landmines, and other concealed metallic munitions. To discriminate hazardous objects from innocuous items, we first fit a physics-based phenomenological mathematical model to geophysical data. Among the most widely used models for subsurface metallic target detection and discrimination is an infinitesimal dipole approximation. In this model, we approximate a target's response with that of a single magnetic polarizability matrix, which behaves like an infinitesimal dipole when excited by a primary (transmitted) field. The greatest advantage of the dipole model is that it is simple and imposes low computation cost. However, researchers have recently begun to realize the limitations of the simple dipole model as an inherently coarse description of the EMI behavior of complex, heterogeneous targets like UXO or explosive metallic targets. To minimize these limitations, we present the application of a physically complete model that represents the responses of an object under interrogation by vehicle-mounted EMI arrays, such as Single-transmit Multiple-receiver (STMR) and MetalMapper arrays. Associated inversion and discrimination methods are extremely fast, especially when the number of unknowns is minimized. Applicability of the models with respect to computational speed and accuracy for both single and multiple targets are compared with those from infinitesimal dipole approximations.

7664-10, Session 1

Dual-EMI system for object classification

J. A. Marble, I. T. McMichael, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Two vehicle mounted metal detector arrays are used in conjunction to perform object classification. The first array (Vallon VMV-16) contains small coils for detecting shallow targets. The second array (Minelab STMR II) contains receive coils of roughly the same size, but a single large transmitter for detecting deep targets. These two sensors are used together to classify objects as: "SHALLOW and LARGE","DEEP and LARGE", or "SHALLOW and SMALL". SHALLOW/DEEP implies the depth of the object; SMALL/LARGE implies the metal content. These object classes are further specified within the paper. An experiment is performed using unexploded ordnance (UXO) and shallow buried calibration objects. The UXO ranges in depth from flush buried to 48". The calibration targets consist of various rods, disks, and cylinders ranging in depth from flush buried to 12". A confusion matrix is produced showing the percentage of correct classification for the various objects.

7664-11, Session 2

Upward projection of EMI data for sensing of subsurface UXO in cluttered, multi-object cases

K. A. O'Neill, B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); F. Shubitidze, J. P. Fernández, I. Shamatava, Dartmouth College (United States); T. M.

Grzegorczyk, Delpsi, LLC (United States)

In subsurface UXO sensing, single field (SF) or multi-static data arises when a single excitation field produces a single, spatially distributed response field that is sampled from a number of locations. Upward continuation (UC) of SF EMI data has shown distinct benefits in suppressing the relative strength of clutter. It also brings the response of a larger, deeper object to the fore when shallower, smaller targets are also present. In contrast to SF EMI, in mono-static EMI the transmitters and receivers are attached and move together. Each data point refers to a different response field stimulated by a correspondingly different target excitation. Upward projection (UP) of such data does not extend a SF but rather computes the data that would be obtained from diverse response fields, as if the instrument were deployed over space at higher elevations. Here we present new formulations to extend UC to accomplish UP of mono-static data. Tests with synthetic and actual data evaluate UP methods for theoretical and practical feasibility, clutter reduction, and isolation of signals from a single contributing objects in multi-object cases. UC and UP are applied to emerging multi-static and mono-static instruments.

7664-12, Session 2

Sparse model representations of target signatures for improved landmine detection using frequency domain electromagnetic induction sensors

S. L. Tantum, P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Frequency-domain electromagnetic induction (EMI) sensors have the ability to provide target signatures which enable discrimination of landmines from harmless clutter. In a model-based signal processing paradigm, the target signatures can be decomposed into a weighted sum of parameterized basis functions, where the basis functions are intrinsic to the target under consideration and the associated weights are a function of the target sensor orientation. The basis function parameters can then be used as features for classification of the target as landmine or clutter. One of the challenges associated with effectively utilizing frequency-domain EMI sensor data within a model-based signal processing paradigm such as this is determining the correct model order for the measured data, as the number of basis functions intrinsic to the target under consideration is not known a priori. In this work, relevance vector machine (RVM) regression is applied to simultaneously determine both the number of parameterized basis functions and their relative contributions to the measured signal. The target may then be classified utilizing the basis function parameters as features within a statistical classifier. Results for data measured with a prototype frequency-domain EMI sensor at a standardized test site are presented. Preliminary results indicate that RVM regression followed by statistical classification utilizing the resulting model-based features provides an effective approach for classifying targets as landmine or clutter. [This work is supported by the US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD).]

7664-13, Session 2

Measured dipole expansion of discrete relaxations to represent the electromagnetic induction response of buried metal targets

W. R. Scott, Jr., G. D. Larson, Georgia Institute of Technology (United States)

Broadband electromagnetic induction (EMI) sensors have been shown to be able to reduce false alarm rates and increase the probability of detecting landmines. The broadband responses of many targets have been studied and shown to be relatively invariant to burial depth.

However, little is known about how landmines and complex clutter objects behave when they are tilted at odd angles, potentially resulting in missed detections. To aid in the development of the EMI sensors and associated detection algorithms, a testing facility and an inversion technique have been developed to characterize the response of typical targets and clutter objects with respect to location, orientation, and frequency. The data from these measurements will be used to study the response of the targets and develop models that are valid for any orientation of the object. This type of measurement would be very difficult to perform in the field due to the difficulty of accurately placing and rotating the target. The models are simple sets of magnetic dipoles with discrete relaxation frequencies. Results will be presented for a range of targets such as shell casings, wire loops, and landmines. It is envisioned that the models derived in this work will be utilized to reduce false alarm rates and increase the probability of detection for EMI sensors through improvements in both the hardware and the processing algorithms used to detect and discriminate buried targets.

7664-14, Session 2

Application of Lp-regularized least squares for 0<=p<=1 in estimating discrete spectrum of relaxations for electromagnetic induction responses

M. Wei, W. R. Scott, Jr., J. H. McClellan, G. D. Larson, Georgia Institute of Technology (United States)

The EMI response of a target can be accurately modeled by a sum of real exponentials. However, it is difficult to obtain the model parameters from measurements when the number of exponentials in the sum is unknown and the summands are highly correlated. Traditionally, the time constants and residues are estimated by nonlinear iterative search. Most of these methods, however, often suffer from (a) sub-optimal solutions that are far from the truth and (b) complex parameters that do not have physical meaning.

In this paper, the estimation problem is reformulated into a linear system by enumerating the relaxation parameter space. The model parameters are then estimated through a modified Lp-regularized least squares algorithm for $0 <= p <= 1$. Using tests on synthetic data and laboratory measurement of known targets the proposed method is shown to provide satisfactory and stable estimates of the model parameters. From the lab data, we demonstrate that the proposed method can correctly estimate the relaxation time constants of a target, which is of great value as the time constants are position and orientation invariant and can be used as features in target discrimination.

We also propose an empirical method to select the regularization parameter to the Lp-regularization problem. The resulting selection rule has the logged regularization parameter in a linear relationship with the noise level. This simple relationship allows the proposed method be applied in practice with short computation time while being robust.

7664-15, Session 3

Detection of buried mines and explosive objects using dual-band thermal imagery

J. J. Lepley, M. T. Averill, J. J. Hay, M. E. Bray, SELEX GALILEO (United Kingdom)

Thermal imagery detects material and thermal properties of the scene that can be interpreted to provide information on the presence of buried or surface-laid IED threats. Surface signatures above buried objects include: changes in surface moisture content, altered soil porosity resulting from the emplacement and alteration of the physical mixture of the surface soil through the disturbance of silicate particles that exhibit Restrahlen discontinuities.

We have developed a dual-band thermal imager (CONDOR II) capable of imaging in both the Medium (3-5μm) and Long band (8-12μm) at full TV resolution and frame rates on a common focal plane array. The two bands each respond differently to the thermal black-body and emissivity of the materials in the scene; by selectively processing the information present in the two bands we extract information on the physical nature of the materials being imaged.

We described the development of a statistical technique to process the information present in the two bands to extract the different physical properties recorded within each band. The information, once processed and re-laid over the original, demonstrates an enhanced visibility of surface signatures that is resilient to changing lighting conditions over the diurnal cycle. We present the development of a statistical classifier used to detect targets on independently trained images with a high probability of detection and low false negative rates. The paper also includes work on processing techniques to further mitigate the impact of false positives through the selective processing of image regions and contextual interpretations of the scene content.

7664-16, Session 3

Shortwave infrared detection of disturbed soils

C. A. Hibbitts, The Johns Hopkins Univ. (United States); J. J. Staszewski, Carnegie Mellon Univ. (United States)

Objects buried in unimproved surfaces can be inferred from the disturbance of the soil above them. We have found that shortwave infrared (SWIR) imaging, filtered from 1.5-1.7 μm, is adept at detecting mines emplaced according to U.S. military doctrine in moist temperate soils. The signature is a darkening of the surface where disturbed and likely is a result of multiple interclast reflections reducing the effective albedo of the rougher disturbed soil relative to smooth, less disturbed soil. The salience of the low-albedo signature of disturbed soil is emphasized by the generally low-contrast of adjacent undisturbed soils. Rocks, minerals, and vegetation detritus are similarly bright at this wavelength, and therefore the lower albedo of a disturbed soil can often be discerned against this bland background. However, there is an illumination dependency. At very low sun angles (near sunrise and sunset) the low amplitude topography and small clasts/stones, cast shadows that disrupt and obscure the signature of the disturbed soil. There may also be a reduction in the salience of the signature at high sun angles, when few shadows (or multiple reflections) occur. We are continuing to test the efficacy of SWIR imaging for detecting disturbances of other soil types and under varying illumination conditions.

7664-17, Session 3

Field observations and radiative transfer modeling of LWIR disturbed soil spectra

P. G. Lucey, Univ. of Hawai'i (United States); E. M. Winter, Technical Research Associates, Inc. (United States)

The spectral distinctiveness of disturbed soil can be an important tool for the detection of buried mines, however, the detailed mechanism behind the phenomenon is not completely understood. A leading notion has been that soil disturbance causes soil particles to be coated with clinging fines ("dirty dirt"), somehow reducing contrast. We took photomicrographs of disturbed and undisturbed surfaces in the field that showed the spectral effects and found that not only clinging fines on larger particles are present in the disturbed soil but, in certain desert environments, size differences between particles in disturbed and undisturbed states. Disturbed soil of this latter category will likely persist for longer periods of time, with lower levels of weathering due to rain. A spectral modeling approach was used to explain these observations. The spectral emissivity of soils in the region of thermal emission from 8-14 micrometers is a combination of the spectral emission of the mineral and other components in the soil, as well as their physical arrangement and the thermal state of the soil (presence of thermal gradients). In this paper, we will outline the procedure for producing a spectral model of a mixed

soil, and show examples of model soils compared to measured soils with the two major soil constituents: quartz and clay. The predictions of this theory are then compared to field measurements made with a LWIR Spectrometer of disturbed and undisturbed soil.

7664-18, Session 3

MOMS: a multi-optical sensor system for detection of surface laid mines

D. Letalick, I. G. Renhorn, O. Steinvall, N. Wadströmer, Swedish Defence Research Agency (Sweden)

The multi-optical mine detection system (MOMS) is a research project focused on the detection of surface laid mines. In the sensor suite, both passive and active sensors are included, such as IR as well as hyper- and multispectral cameras, and 3-D laser radar.

Extensive field experiments have been conducted to collect data under various environmental conditions. Three seasons have been covered during the field campaigns: Spring, Summer, and Autumn. Furthermore, the mines have been arranged in three different types of vegetation scenarios. Also, a long term data collection effort has been conducted to collect diurnal and seasonal signature variations.

Among the signal processing techniques considered, anomaly detection emerges as a key component in a system concept. This method detects things that are different from what is expected (the background) and thus gives a first indication of possible mines. The detected anomalies are then analyzed further, by using certain assumptions concerning the targets, e.g. their expected size. This leads to the detection of mine-like objects.

Different sensor suites have been studied and a concept for an optical mine detection system is proposed. In this paper we present some of the results from the project.

7664-19, Session 4

Experiential study of the detection of buried landmines in soils with increasing water content by infrared imaging

E. H. Castro, D. J. Dadamia, Univ. de Buenos Aires (Argentina)

It is well known that metallic or plastic landmines buried to a certain depth in soil can be detected by infrared imaging during warming or cooling of the soil.

The detection of buried landmines are influenced by the properties of the soil that surrounds the mine. The temporal and spatial variability in soil properties accounts for a significant part of the detection uncertainty that is associated with most sensing methods. In particular, ground-penetrating radar and thermal infrared imaging are affected by the water content of the soil.

Infrared detection and identification of the mines is dependent of the material of the mine, metallic or plastic, and of the composition and water content of the soil.

We have obtained infrared images of cylindrical metallic and plastic objects, buried at the same depth in soils of different composition, including sand, during the cooling process. We have filled containers with different types of soils, buried the objects, warmed the soil with the objects by exposition to solar radiation during half an hour and then screened the radiation to allow cooling and obtained images in the 8-12 micrometer spectral interval every 5 minutes. After this, we have repeated the process increasing the content of water of the soil until it was difficult to detect and identify the object.

The infrared images were processed, analysed to detect shape and dimensions for every soil and water content, and the results are discussed. Conclusions of the study are presented.

7664-21, Session 4

Detection of disturbed earth using active and passive polarimetric imaging

K. P. Gurton, M. A. Felton, Jr., A. J. Raglin, U.S. Army Research Lab. (United States)

We report results of an ongoing study designed to assess the utility for using passive or active polarimetric imaging for the detection of recently buried landmines and/or improvised explosive devices (IED) devices. Test surface(s) considered range from a generic sand based surface to a conventional road surface consisting of a gravel-clay-soil mixture. We investigate the polarimetric signature in two distinctly different wave-band regions, i.e., image capture using active NIR (approx. 0.8μm) illumination, or capture in the LWIR (7.5-11.1μm) using both passive and active illumination. Stokes images, S0, S1, and S2, are recorded in both bands. The LWIR uses two different systems that are based on a spinning achromatic retarder design, where one system uses a Mercury Cadmium Telluride focal-plane-array, and the other uses a microbolometer FPA. NIR polarimetric signatures are measured using a standard NIR CCD, where the polarimetric filtering is acquired by the mechanical rotation of a polarizer/wave-plate set of optics. Tests consist of burying various surrogate targets approximately 0.20 cm below the surface, where great care is taken to camouflage the area as to eliminate any "visible" signs of disturbance. Thermal gradients resulting from the unearthing of the soil are allowed to dissipate before polarimetric data is recorded. Two different detection metrics are presented for comparison, 1) conventional receiver operating characteristic (ROC) curve detection analysis, and 2) an effective contrast ratio between the target and background.

7664-22, Session 4

Disturbed soil characterization workshop: post-meeting summary

J. M. Cathcart, Georgia Institute of Technology (United States)

Disturbance of ground surfaces can arise from a variety of processes, both manmade and natural. Burying landmines, vehicle movement, and walking are representative examples of processes that disturb ground surfaces. The nature of the specific disturbance process can lead to the observables that can aid the detection and identification of that process. While much research has been conducted in this area, fundamental questions related to the remote detection and characterization of disturbed soil surfaces remain unanswered. Under the sponsorship of the Army Research Office (ARO), the Night Vision and Electronic Sensors Directorate (NVESD), and the U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC), Georgia Tech hosted a workshop to address Remote Sensing Methods for Disturbed Soil Characterization. The workshop was held January 15-17, 2008 in Atlanta. The primary objective of this workshop was to take a new look at the disturbed soil problem in general as well as its relation to buried explosive detection and other manmade disturbances. In particular, the participants sought to outline the basic science and technology questions that need to be addressed across the full spectrum of military applications to fully exploit this phenomenon. This presentation will outline the approach taken during the workshop and provide a summary of the conclusions.

This work is supported under a grant from the US Army Research Office.

7664-23, Session 4

Analysis and comparison of disturbed soil signatures from two field sites

A. M. Thomas, J. M. Cathcart, Georgia Institute of Technology (United States)

An analysis is performed and presented on disturbed soil data collected

at test sites in Arizona in 2007 and in Hawaii in 2008. Both data sets were collected using the University of Hawaii's Airborne Hyperspectral Imager (AHI) operating in the long wave infrared. In addition, supporting ground truth data was taken at both test sites using a D&P infrared field spectroradiometer (covering the 3.0 - 12.0 micron wavelength region), a thermal infrared camera, and a shortwave infrared camera. Targets at these sites included holes, trenches, camouflage, false targets, and disturbed vegetation. Differences in the spectral signatures of disturbed soil and other objects at the two sites are highlighted.

This work is supported under a grant from the US Army Research Office.

7664-24, Session 4

Common IED exploitation target set (CIEDETS) disturbed earth model verification and validation (V&V)

Z. S. Wowczuk, P. M. Franken, A. J. Harrison, ARES Systems Group, LLC (United States)

Open-air, field testing of C-IED ISR systems is increasingly focused on the detection of disturbed earth targets representing IED emplacements. The base understanding of the detection phenomena for various modalities of electro-optics/infrared (EO/IR) systems has been investigated and tested in several open-air exercise sponsored by Joint-IED Defeat Organization (JIEDDO) and other C-IED defeat agency's. A model has been developed to evaluate the pre-test target layout planning for multiple modalities with specific concentrations on disturbed earth.

This paper outlines the work performed during the initial (V&V) process for the CIEDETS test-planning model. It includes using government furnished (GF) ground truth data collected during open-air test events correlate with sensor meta-data to validate system probability of detection (Pd) against specific targets. The modalities evaluated in this activity included visible and mid-wave infrared (MWIR) bands. A comparison study between (1) pixel intensity analysis and (2) the CIEDETS model will provide a confidence margin assessment for the emplacement buried CIEDETS model.

7664-25, Session 5

Boosted weak learners for automatic target recognition

J. C. Isaacs, Naval Surface Warfare Ctr. Panama City Div. (United States)

AdaBoost, short for Adaptive Boosting, is a machine learning algorithm, formulated by Yoav Freund and Robert Schapire. It is a meta-algorithm, and can be used in conjunction with many other learning algorithms to improve their performance. AdaBoost is adaptive in the sense that subsequent classifiers built are tweaked in favor of those instances misclassified by previous classifiers. AdaBoost is somewhat sensitive to noisy data and outliers. Otherwise, it is less susceptible to the overfitting problem than most learning algorithms. Experiments were performed on the boosting of several weak learning methods. Results demonstrate that the boosting of several weak learners leads to a drastic improvement for both probability of classification and false alarm reduction in ATR applications over using these weak learners without boosting.

7664-26, Session 5

Neyman Pearson detection of K-distributed random variables

J. D. Tucker, Naval Surface Warfare Ctr. Panama City Div. (United States) and Colorado State Univ. (United States); M. R. Azimi-Sadjadi, Colorado State Univ. (United States)

(For G. Dobeck's Session on Sonar ATR) Detection and classification of underwater objects in sonar imagery is a complicated problem due to various factors such as variations in operating and environmental conditions, presence of spatially varying clutter, variations in target shapes, compositions, and orientation. Moreover, due to the enhanced sonar resolution bottom features can totally obscure a mine-like object. Recent studies have indicated that different bottom types exhibit non-Gaussian probability distributions depending on the grazing angle, sonar frequency and range for sonar imagery. Specifically, the K-distribution has shown to be a good assumption for the distribution of Synthetic Aperture Sonar (SAS) imagery. In this paper a new detection method for side-looking sonar imagery is developed for K-distributed random variables. The corresponding equations for the log-likelihood and J-divergence are derived and compared to the corresponding counterparts derived the Gaussian and Rayleigh assumptions. Test results of the proposed methods on a data set of synthetic underwater side-scan sonar images will be presented. This database contains images varying degree of difficulty and bottom clutter and backgrounds generated using a correlated K-distributed model. Results illustrating the effectiveness of the K-distributed detector as the optimum detection tool will be presented in terms of probability of detection, false alarm, and correct classification rates for various bottom difficulty types.

7664-27, Session 5

Recent ATR algorithm improvements for side-scan sonar imagery

T. Aridgides, M. F. Fernández, Lockheed Martin Maritime Systems & Sensors (United States)

An improved automatic target recognition (ATR) processing string has been developed. The overall processing string consists of pre-processing, subimage adaptive clutter filtering, normalization, detection, feature extraction, optimal subset feature selection, feature orthogonalization and classification processing blocks. The objects that are classified by three distinct ATR strings are fused using the classification confidence values and their expansions as features, and using "summing" or log-likelihood-ratio-test (LLRT) based fusion rules. These three ATR processing strings were individually developed and tuned by researchers from different companies. The utility of the overall processing strings and their fusion was demonstrated with an extensive shallow water side-scan sonar dataset.

In this paper we describe new processing improvements: four additional classification features are extracted, using target shadow information and a feature extraction window whose length is now made variable as a function of range. This new ATR processing improvement resulted in a 1.8:1 reduction in false alarms. Two advanced fusion algorithms are subsequently applied. First, a nonlinear Volterra expansion (2nd order) feature-LLRT fusion algorithm is employed. Second, a repeated application of a subset Volterra feature selection / feature orthogonalization / LLRT fusion block is utilized. It is shown that the cascaded Volterra feature-LLRT fusion of the ATR processing strings outperforms baseline "summing" and single-stage Volterra feature-LLRT algorithms, yielding significant improvements over the best single ATR processing string results, and providing the capability to correctly call the majority of targets while maintaining a very low false alarm rate.

This work was sponsored by the Office of Naval Research (ONR 321OE, ONR 32MIW). The technical agent was NSWC, Panama city (POC: Dr. Gerald J. Dobeck).

7664-28, Session 5

Multichannel imager for littoral zone characterization

Y. Podobna, J. Schoonmaker, J. J. Dirbas, J. Sofianos, C. D. Boucher, Advanced Coherent Technologies LLC (United States)

This paper describes an approach to utilize a multi-spectral electro-

optical system for littoral zone characterization. Advanced Coherent Technologies, LLC (ACT) presents the Multi Channel Imager (MCI) for the surf zone environmental assessment and potentially surf zone target detection. Specifically, an approach is presented to determine a surf zone index (SZI) from the multichannel sensor. SZI provides a single quantitative value of the surf zone conditions delivering an immediate understanding of the area and an assessment as to how well an airborne optical system might perform in a mine countermeasures operation. Utilizing consecutive frames of SZI images ACT is able to measure variability over time. A surf zone nomograph which incorporates targets, sensor and environmental data including the SZI to determine the environmental impact on system performance is reviewed in this work. ACT's electro-optical multi-channel imaging system and test results are discussed and presented.

7664-29, Session 5

Inspecting the inside of the objects on the sea floor

V. Valkovic, R. Kollar, D. Sudac, K. Nad, J. Obhodas, Institut Ruder Bo?kovic (Croatia)

In order to demonstrate the possibility of identifying the material within the objects on the sea floor we have performed tests with the 14 MeV sealed tube neutron generator incorporated inside a small submarine, SURVEYOR, submerged in the test basin filled with sea water. The materials inside the investigated objects were identified by measuring the gamma ray spectra and by using the window on the measured alpha-gamma time spectrum.

The existence of a data base of potentially explosive devices on the floor of coastal sea, especially ports and waterways, is of paramount importance. However, the sea floor is littered by number of different objects and the water is not very transparent on such locations. This makes the identification of objects extremely difficult even on known locations. We discuss how to position the SURVEYOR when the object investigated for the presence of explosive has been identified by other sensors (camera, sonar, magnetometer, etc.).

The SURVEYOR needs to be positioned in such a way that it can detect the presence of explosive, its type and quantity (volume). To accomplish this mission the amount of iron and water between the neutron probe and threat material needs to be minimized and the Surveyor needs to investigate the part of device containing explosive charge. Examples are shown for objects found on the eastern part of Adriatic coastal sea: grenades - shell only, grenades - combination, ant ship mines - anchored, anti ship mines - lying on the sea floor, torpedoes, airplane bombs and barrels.

7664-30, Session 5

Performance metrics for state-of-the-art airborne magnetic and electromagnetic systems for mapping and detection of unexploded ordnance

W. E. Doll, D. T. Bell, T. J. Gamey, L. P. Beard, J. R. Sheehan, J. Norton, Battelle (United States)

Over the past decade, notable progress has been made in the performance of airborne geophysical systems for mapping and detection of unexploded ordnance in terrestrial and shallow marine environments. For magnetometer systems, the most significant improvements include development of denser magnetometer arrays and vertical gradiometer configurations. Prototype analyses and recent Environmental Security Technology Certification Program (ESTCP) assessments using new production systems have demonstrated that better performance can be achieved with vertical gradient configurations of magnetometers, rather than horizontal gradiometer configurations or total field configurations. Comparison of field results show that the greatest sensitivity is achieved with small horizontal separation between the vertical gradiometer "pods", despite modeling results which suggest that horizontal gradiometers would be superior.

A good as magnetometer systems have proven to be at many sites, they are inadequate at sites where basalts and other ferrous geologic formations or soils produce anomalies that approach or exceed those of target ordnance items. Additionally, magnetometer systems are ineffective where detection of non-ferrous ordnance items is of primary concern. Recent completion of the Battelle TEM-8 time-domain electromagnetic system represents the culmination of nearly nine years of assessment and development of airborne electromagnetic systems for UXO mapping and detection. A recent ESTCP demonstration of this system in New Mexico showed that it was able to detect 109 out of 110 blind-seeded ordnance items, 81mm and larger, and that it could be used to map in detail a bombing target on a basalt flow where previous airborne magnetometer surveys had failed. The probability of detection for the TEM-8 in the blind-seeded study area was better than that reported for a horizontal magnetic gradiometer demonstration of the same blind-seeded site, and the TEM-8 system successfully detected these items with less than half as many anomaly picks as the horizontal magnetic gradiometer system.

Overall, improvements in airborne geophysical systems over the past ten years have led to the capability of detecting smaller ordnance with fewer false positives. These trends should continue as more technological advances are made.

7664-31, Session 5

Assessing EMI noise due to the marine environment to enhance underwater UXO detection and discrimination

A. Bijamov, F. Shubitidze, J. P. Fernández, I. Shamatava, Dartmouth College (United States); B. E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); K. A. O'Neill, Dartmouth College (United States)

The main objective of this work is to assess the noise level due to the marine environment in underwater UXO discrimination studies. Marine environments tend to exhibit several electrically different layers ("pancakes") because of salt intrusions, haline fronts in shallow areas like river estuaries, and bottom layers. Salt intrusions and fingers as well as haline fronts are typical of the coastal ocean and result in high salinity gradients. The EMI field thus behaves in a marine environment much as it does in a layered medium. Strong vertical gradients of salinity may increase the false-alarm ratio and reduce the effectiveness of the detection and discrimination process. Consequently, seafloor haline structures must be taken into account and their effects suppressed during both wide-area assessment and detailed surveys. The investigation is undertaken in both frequency and time domains using respectively the frequency-domain MAS with a surface impedance boundary condition and an alternating direction implicit finite-difference time-domain (ADI-FDTD) method. The ADI-FDTD method is a stable technique compared to the conventional FDTD method even when the Courant-Friedrichs-Lewy condition is not satisfied for spatial and time steps. The studies are carried out using virtual GEM-3D and TEMTADS sensors to illuminate objects at various locations and orientations, both in free space and in conducting host media. The dielectric permittivity of a conducting medium is modeled using the Debye dielectric relaxation model in both FD and TD domains. In particular, the conductivity of saltwater is determined using realistic values of temperature and salinity. The methods are also adapted to rough surfaces in order to investigate the noise associated with surface roughness and with moving targets and surfaces. Finally, comparisons between FD and TD modeled data, as well as with measured data, are presented.

7664-32, Session 5

Adaptive large-scale clutter removal from imagery with application to high-resolution sonar

G. J. Dobeck, Naval Surface Warfare Ctr. Panama City Div. (United States)

The high-resolution side-scan sonar and the high-frequency synthetic-aperture sonar are two important sensors used for sea mine detection and classification. The ability to discriminate bottom targets in imagery collected from these sonars is especially difficult in littoral environments where there is large-scale clutter and complex sea bottom textures; e.g., sand ripple or coral beds. Detection and classification would benefit from an adaptive denoising algorithm that would remove such background artifacts. This paper presents a Fourier-based denoising algorithm that removes features in the image that are of larger scale than the expected target size. The algorithm uses a data-driven soft-thresholding technique. The large support of the Fourier bases is used to capture and remove large-scale artifacts while leaving the target-size features nearly unchanged. Preliminary investigations have demonstrated excellent performance. The algorithm is computationally fast and suitable for real-time application. It is general in nature and can be applied to other types of imaging sensors; e.g., SAR. This work was sponsored by the Office of Naval Research (ONR 321OE).

7664-33, Session 5

A method to generate synthetic aperture sonar images with parameterized autocorrelation functions

J. T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

(For inclusion in Gerry Dobeck's ATR session) In this paper we propose a method to generate synthetic aperture sonar images with known parameterized autocorrelation functions (ACF). Using a parameterized autocorrelation function for a gamma random variable, a nonlinear mapping produces a set of Gaussian correlation coefficients. The Gaussian correlation coefficients are used to produce a correlated two-dimensional Gaussian random variable. The correlated Gaussian random variable is mapped to a correlated gamma random variable by equating the respective distribution functions. Finally a correlated K-distributed random variable is produced by forming a product between the correlated gamma-distributed random variable and an uncorrelated exponential random variable. ACFs estimated from the synthetic images are compared to the true ACF in terms of mean-square error.

7664-34, Session 5

Modified Fisher-fusion techniques to improve the individual performance of sonar computer-aided detection/computer-aided classification (CAD/CAC) algorithms

C. M. Ciany, W. C. Zurawski, Raytheon Co. (United States)

Raytheon has extensively processed high-resolution sidescan sonar images with its CAD/CAC algorithms to classify mine-like objects (MLOs) in a variety of underwater environments. This algorithm segments the image into candidate highlight and shadow regions of interest (ROIs), and extracts and scores features from these ROIs. The MLOs are classified by thresholding an overall classification score, formed by summing the individual feature scores. The algorithm performs reliably against MLOs that exhibit highlight and shadow regions that are both distinct relative to the ambient background. However, the sonar images for many real-world undersea environments can contain a significant percentage of MLOs exhibiting either "weak" highlight or shadow regions. Robust performance in these environments is achieved by tailoring the individual feature scoring algorithms to optimize the separation between the corresponding highlight or shadow feature scores of targets and non-targets. This study examines modifications to a previously presented alternate approach that employs Fisher fusion principles to generate optimal weighting coefficients which are applied to the individual feature scores before summing. Results from processing of at-sea data sets are presented that demonstrate the performance benefits obtained from the modifications.

7664-92, Session 5

Acoustically induced seismic waves for mine detection in littoral environments

J. M. Sabatier, Army Research Lab. (United States); R. D. Burgett, I. Aranchuk, The Univ. of Mississippi (United States)

The phenomenon of the coupling of airborne sound into the ground to detect mines buried in a beach environment has been investigated. Measurements to acoustically characterize the beach included the acoustic-to-seismic coupling transfer function (S/A TF) and Rayleigh wave speed. A laser Doppler vibrometer was used to measure velocity profiles over a buried anti-tank mine when a loudspeaker was used to excite ground vibrations. As the sensors were moved from the high tide water mark to the low tide water mark, the amount of water in the beach sand increased and the Rayleigh wave speed decreased. The resulting decrease in shear wave speed caused the sand to be more fluid-like and velocity minima and maxima in the S/A TF were minimized. The result was a more uniform background velocity that should allow for easier target detection. We present velocity profiles over the target, Rayleigh wave speeds, the S/A TF and explanations of the more uniform TF.

7664-35, Session 6

AMDS: user perspective

C. Hollister, U. S. Army Maneuver Support Ctr. (United States)

No abstract available

7664-36, Session 6

Ground penetrating radar and electromagnetic induction sensors for anti-tank and anti-personnel landmine detection

A. Etebari, B. Whaley, H. Ghods, M. W. Hibbard, NIITEK, Inc. (United States)

Ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors represent the state-of-the-art in stand off landmine detection. These technologies are readily available for both hand held and vehicle mounted detection. The pairing of these two technologies yields great advantages in both probability of detection (Pd) and false alarm rate (FAR) reduction. This paper will present an overview of NIITEK's low-radar-cross-section ultra-wideband impulse radar and electromagnetic induction sensor, i.e. SEMISense. Our GPR technology, based on the Wichmann antenna, exhibits several characteristics that make it ideal for low metal anti-tank (AT) landmine detection. These are: (1) Ultra-wide-bandwidth impulses (200MHz to 7 GHz bandwidth); (2) Excellent signal to clutter ratio; and (3) Extremely low-radar-cross-section. To complement this technology, SEMISense, a state-of-the-art EMI detector, has been developed. The sensor is is a quadrapole pulsed frequency domain sensor that operates with a bandwidth of 100 kHz and has a dynamic range of 120 dB, allowing detection of extremely low metal anti-personnel (AP) landmines. The coil array consists of one transmit and three receive coils. Recent accomplishments related to this sensor will be presented.

7664-37, Session 6

NIITEK-NVESD AMDS program and interim field-ready system

M. W. Hibbard, A. Etebari, NIITEK, Inc. (United States)

NIITEK (Non-Intrusive Inspection Technology, Inc) develops and fields vehicle mounted landmine detection systems. Since 2003, the NIITEK has developed and tested a remote robot-mounted mine detection system for use in the NVESD AMDS program. This paper will discuss the road map of development since the outset of the program, including transition from a data collection platform towards a militarized field-ready system for immediate use as a remote counter-mine solution with real-time threat detection. The system has been integrated on both the iRobot Packbot and the Foster-Miller Talon robot. This brief will discuss the requirements for a successful near-term system, the progressive development of the system, our current real-time capabilities, and our planned upgrades for moving into and supporting field testing, evaluation, and ongoing operation.

7664-38, Session 6

Autonomous mine detection system (AMDS) incorporating SFCW GPR and CWMD sensors for discrimination

D. O. Carlson, H. A. Duvoisin III, K. L. Johnson, M. Trishaun, L-3 CyTerra (United States)

Landmines have been laid in conflicts around the world and continue to maim or kill civilians and soldiers. Metal detectors (MD) have been used successfully to detect mines, but have difficulty detecting mines with little or no metal content. Ground penetrating radar (GPR) systems have successfully been used to supply detection capabilities where metal detectors fail. Handheld devices using such sensors have historically been used in battle but they can put the user at high risk under direct fire from the enemy while exposed during some operations. We describe a robotic, explosive hazard, anti-personnel/anti-tank mine detection system featuring dual-sensor GPR/MD capability for enhanced mine detection and for removing the soldier from the mine field.

The MD is a broadband electromagnetic induction continuous wave sensor to help discriminate between buried landmines and metal clutter. The sensor operates in the frequency domain and collects data at 21 logarithmically spaced frequencies from 300 Hz to 90 kHz. The GPR is a broadband stepped frequency continuous wave (SFCW) sensor operating from 700 MHz to 4 GHz in 10 MHz steps. The GPR employs an array of low cross section inverted V-dipoles swept over the scene. The GPR data will also support 3D synthetic aperture radar (SAR) imagery to aid in user target verification.

By fusing features from the GPR and MD measurements we show probability of detection versus false alarm rates on a limited data set from both a local CyTerra target/clutter grid emplacement and USA field sites.

7664-39, Session 6

Trace detection of explosives using an in-line, high-volume sampler, preconcentrator, and Fido detector

R. Ingram, J. Sikes, ICx Nomadics, Inc. (United States)

This paper will present the results of a project to develop a prototype system to detect explosive objects and obscured contaminated targets. By combining a high volume sampling nozzle with an inline two-stage preconcentrator and a Fido explosives detector, greater standoff is achieved than with the Fido alone. This prototype is being developed under the auspices of US Army Night Vision and Electronic Sensors Directorate (NVESD) Countermine in conjunction with other detection

technologies as part of the risk reduction effort under the Autonomous Mine Detection System (AMDS) program.

This device is one of several detection tools and technologies planned for AMDS. AMDS robotic systems will have multiple, and at times, overlapping objectives. One objective is to detect trace amounts of explosives from the surface of a potential target. Current detectors used on robotic systems must either be directly in the explosive's vapor plume or make direct contact with the target. By increasing the distance between the target and the detector, the manipulation of the robot deploying the detector is less critical.

In addition to a high probability of detection and low false alarm rate, the successful detector in the program must overcome cross-contamination, turn-around time, and environmental issues. The detector could be used not only for AMDS, but on virtually any robotic platform with an articulated arm and modest payload capability.

The paper shall provide preliminary results of the prototype system to include data and where feasible, video of test results.

7664-40, Session 6

Microcantilever sensor platform for UGV-based detection

K. K. Mahmud, P. S. Schuler, T. T. Lawrence, A. D. Oliver, E. P. Geraghty, A. E. Halleck, Triton Systems, Inc. (United States); D. R. Hicks, U.S. Army Night Vision & Electronic Sensors Directorate (United States); V. M. Maksimovic, Northrop Grumman Mission Systems (United States)

The increased use of Unmanned Ground Vehicles (UGVs) drives a need for new light weight, low cost sensors. Microelectromechanical System (MEMS) based microcantilever sensors are a promising technology to meet this need, because they can be manufactured at low cost on a mass scale, and are easily integrated into a UGV platform for detection of explosives and other threat agents. While a variety of microcantilever technologies are currently available, we have determined that an integrated piezoresistive readout offers the best path to integration with UGV systems. The technology is extremely sensitive, down to parts per trillion levels. Selectivity is a major challenge and is being addressed by a combination of sampling techniques and specific coatings on the microcantilever surface. Improvements in sampling techniques involve systems to eliminate or minimize moisture and dust particle entry, methods for temperature stabilization, and methods for reducing and correcting temperature related drift. Microcantilever responses are complex and a significant effort has been made to develop guidelines for measurement of appropriate responses to reduce false positives and false negatives. This work summarizes advances in deconvoluting ultra-sensitive microcantilever responses, proper sampling techniques, and sensor design and cantilever coating methodologies consistent with UGV point detector needs.

7664-41, Session 6

Robot software and hardware architecture for coordinated development of an integrated countermine solution

O. P. Hoffman, iRobot Corp. (United States)

Over the last ten years, iRobot has had significant experience working with various government and industrial partners to integrate various countermine payloads including the Cyterra AN/PSS14, NITEK countermine sensors, Nomadics Fido, SPAWAR Marking systems, NREC manipulators as well as software from various government labs including the INL Robot Intelligence Kernel. In response to the growing requirement to create an architecture both in software and hardware that allows many disparate capability developers to independently develop and then remotely integrate onto iRobot robot platforms, iRobot developed the Aware 2 Robot Intelligence Software and the Robot Developers Kit

which provide a platform for open and integrated capability development across all of iRobot's robots. Specific to the AMDS program, iRobot has developed a payload that provides an integrated set of sensors, computation, hardware interfaces, and software to serve as a basis for an autonomous or semi-autonomous countermine system. In addition to JAUS compatible interfaces that can control multiple different robots, iRobot has developed a software application layer that provides core autonomous capabilities to the countermine system such as map-based supervisory control while also providing the infrastructure to allow third parties to directly integrate applications on top of this layer.

7664-42, Session 6

Remote robotic countermine systems

P. F. Wells, Foster-Miller, Inc. (United States)

QinetiQ North America (QNA) has well over 35 years experience in the mine / countermine mission area. Our expertise covers mine development, detection, and neutralization and has always been intertwined with deployment of remote robotic systems. Our countermine payload systems have been used to detect limpet mines on ship hulls, anti-assault mines in shallow water and littoral zones and currently for clearance and render safe of land-based routes. In our talk, we will address the challenges encountered in addressing the ongoing countermine mission over a diverse range of operational scenarios, environmental conditions and strategic priorities.

7664-43, Session 6

Mine detection performance comparison between manual sweeping and tele-operated robotic system

H. Herman, Carnegie Mellon Univ. (United States); T. R. Higgins, O. Falmier, Lincoln Univ. (United States); J. D. McMahill, J. Valois, Carnegie Mellon Univ. (United States)

Mine detection is a dangerous task that is very well suited for robotic application. In the experiment described in this paper, we are trying to answer the question on whether a remote control robotic mine detection system equipped with the same hand-held detector can match the performance of a manually operated detector. To achieve this objective, we have developed the Robotic Mine Sweeper (RMS), which is a robotic platform capable of accurately sweeping and mapping mine lanes using common detectors, such as the F3 Mine Detector or the AN/PSS-14. The RMS is fully remote controlled from a safe distance by a laptop via a redundant wireless connection link. All data collected from the mine detector and various sensors mounted on the robot are transmitted in real-time to the remote user interface and graphically displayed. In addition, a stereo color camera mounted atop the robot is sending a live picture of the terrain, and audio feedback from the detector is presented to the user to further enhance his situational awareness. The user is trained to drag and drop various icons onto the user interface map in order to locate mines and clutters. Using this system, we ran an experiment to compare the detection rate and false alarm of this system compared to those obtained when the operator is physically sweeping the detectors in the field. We will present the results of this study and also our analysis of the result.

7664-44, Session 6

Semi-autonomous mine detection robotic system

H. Herman, Carnegie Mellon Univ. (United States); D. A. Few, R. Versteeg, Idaho National Lab. (United States)

Idaho National Lab and Carnegie Mellon University, along with its

partners, have been developing a semi-autonomous robotic system that is capable of detecting, marking and avoiding land mines. The system currently uses a small robot, such as the Talon or the Packbot, as its mobile platform. But it is designed to be platform agnostic from the start, and can be adapted for use on other platforms of various sizes with very minimal effort. There are several major subsystems that comprise this robot: the modular countermine package, the marking system, the mobile robotic platform, pose estimation and the autonomous navigation software. These subsystems are combined in a flexible architecture to produce the semi-autonomous mine detection and marking behaviors. The key aspects to the flexible architecture are the modular countermine package and the INL Realtime Intelligent Kernel (RIK) software. The modular countermine package contains all the capabilities needed to perform mapping for mine detection, and RIK contains all the capabilities needed to control the mine sweeping behaviors of the robots and to handle the user interface aspect of the robot. We conducted a few experiments to validate the concept and the system, and will present the result of those experiments. We will also provide lessons learned during the development of this complex robotic system.

7664-45, Session 7

CMMAD usability test in support of mine and hazard sensing

D. A. Few, D. I. Gertman, V. G. Walker, Idaho National Lab. (United States)

Leveraging available mine sensor technology and hazards detection capability across multiple robot platforms has great potential for the US Army countermines mission. Over two weeks of field trials, operator usability data were collected in support of lane clearing missions for two robot platforms with Robot Intelligence Kernel (RIK) software and sensor scanning payloads onboard. Control of the robot was performed via a laptop or Wii controller. Soldiers received instructor and hands-on training. The field tests featured autonomous and shared robot autonomy levels where tasking of the robot made use of a graphical interface which featured mine location and sensor readings. In detecting simulated mines, soldiers preferred to use shared mode for search and autonomous mode to return home. In shared mode, they used an Xbox controller. Obstacle density was introduced to determine the efficacy of countermines systems in terms of mobility, search, path planning, detection, and localization. Objective and subjective operator interaction measures included: time, accuracy, workload, situation awareness, distance traveled, rate of advance, joystick usage, time in autonomy mode, and end-user preference. These were derived in accordance with what the war fighter will have to do for different missions in theatre. Similar measures were collected for explosives detection under different line-of-sight conditions. Overall, soldiers felt that the system should be fielded. Results including commentary from soldiers taking part in the study are reviewed in terms of: the applicability of this system to support the countermines mission; insights and lessons learned, trust and preference, and approaches to control interface design.

7664-46, Session 7

Standards and metrics for autonomous countermine systems

I. Chappell, M. May, F. Moses, Institute for Defense Analyses (United States)

The countermine mission is a compelling example of what robots must address to reduce risks that Soldiers take routinely. The list of robot requirements is formidable including autonomous navigation, autonomous sensor scanning, platform mobility and stability, mobile manipulation, multi-robot cooperation, automatic target recognition, and systematic integration and control of components. This paper compares and contrasts how the countermine mission is done today against the challenges of achieving comparable performance using autonomous robots. The Soldier sets a high standard with, for example, over 90%

probability of detecting (Pd) metallic and low-metal mines and a false alarm rate (FAR) similar to .25/m2. What are the issues in having a robot deal with buried and surface-laid landmines as well as buried, concealed, and partially-concealed explosive hazards? How well can we expect to map human performance onto a robotic system? This presentation reviews how robots can achieve comparably high Pd and low FAR using custom automated target recognition algorithms. It also reviews the hard-to-achieve integration of all the robotic components - sensors, platforms, and marking systems along with control of associated error combinations.

7664-47, Session 7

Modular countermine package for small robots

H. Herman, E. T. Henciak, M. J. Licitra, J. D. McMahill, J. Valois, Carnegie Mellon Univ. (United States)

Traditionally, payloads for small robotic platform have been designed as a platform and task specific solution. One issue with this approach is that the payload can not be mounted on a different platform without incurring significant engineering and development efforts. We are trying to address this issue by developing a new modular countermine package that is designed from the ground up to be independent of the platform. The modular package has all the mechanical, electrical and software subsystems for performing mine detection on current and future small robotic platforms. It achieves its modularity by having both programmable front-end and back-end interfaces. On the front-end, it can be equipped with various detection sensors, such as PSS-14 or Minelab F3. On the back-end, it can interface to various robotic platform through standard interfaces, such as Ethernet or serial. It also has a built-in processing unit that can be used to run autonomous navigation software need for countermine behaviors. The modular package also implements mechanical sweeping or positioning of the detector, data interface, registration, pose estimation and sensor map building. These are the capabilities that are needed to be able to perform precise mine sweeping and detection. We have demonstrated this modularity on multiple robotics platforms, including the Talon and the Packbot, and multiple detection sensors.

7664-48, Session 7

Soldier experiments and assessments using SPEAR speech control system for UGVs

J. H. Brown, C. Blanco, A. Juneja, T. Pruthi, L. Ngia, Think-A-Move, Ltd. (United States); O. P. Hoffman, J. Czerniak, iRobot Corp. (United States)

This paper reports on Soldier Experiments and Assessments performed by the Human Research Engineering Field Directorate (HRED) and Maneuver Battle Lab at Ft. Benning, and the Marine Corps Forces Pacific Command Experimentation Center (MEC) at Camp Pendleton evaluating the effectiveness of using speech commands to control an Unmanned Ground Vehicle.

SPEAR, developed by Think-A-Move, provides speech control of UGVs. SPEAR detects user speech in the ear canal with an earpiece containing an in-ear microphone. The system design provides 30 dB of passive noise reduction, enabling it to work well in high-noise environments, where traditional speech systems, using external microphones, fail; it also utilizes a proprietary speech recognition engine. SPEAR has been integrated with iRobot's PackBot 510 and PackBot with FasTac, and with Multi-Robot Operator Control Unit (MOCU), developed by SPAWAR Systems Center Pacific.

These integrated systems allow speech to supplement the hand-controller for multi-modal control of different UGV functions simultaneously.

HRED's experiment measured the impact of SPEAR on reducing the cognitive load placed on UGV Operators and the time to complete specific tasks. Army NCO's and Officer's Candidate School Soldiers participated in this experiment.

The MEC assessment examined speech commands used for two different missions: Route Clearance and Cordon and Search; participants included Explosive Ordnance Disposal Technicians and Combat Engineers. The Marines stated that they benefited from multi-modal control. The Maneuver Battle Lab Assessment examines SPEAR's capabilities in relevant environments.

Overall results of these Assessments are reported in the paper, along with possible applications to autonomous mine detection systems.

7664-49, Session 7

Behavior-based control of robotic payloads for detection, marking, and neutralization of explosive hazards

D. J. Bruemmer, C. W. Nielsen, J. Green, D. Rowe, R. Rowe, Idaho National Lab. (United States)

After decades of effort to provide a robotic countermine capability, the key technology components have been successfully developed but must be brought together into a cost-effective, easy to use product. Work to date includes development of the following components:

1) Sensors that can reliably detect a wide variety of subsurface anomalies;

2) Signal processing and detection algorithms for automating sensor data analysis;

3) Fieldable robotic systems with integrated arms capable of reliably scanning a sensor;

4) Robotic marking systems capable of physically indicating the location of the hazards;

5) Dexterous manipulators that can be mounted on multiple robot systems;

6) Robotic behaviors that can orchestrate the process of navigation, detection, marking, manipulation and mine avoidance.

Critical work remains to integrate these components into a simple, turn-key system that can provide value in the field. For robotic applications in minefield environments and other complex situations, the intelligence needed to provide functional value (i.e. reduced time, increased probability of detection, increased hazard localization accuracy) cannot be derived from a single component or a single behavior. Rather, a principled framework to orchestrate these components and behaviors into a flexible, end-to-end mission capability is necessary.

The goal of 5D Robotics is to coalesce software components related to perception, communication, behavior, world modeling, manipulation, and human interaction into a single behavior framework that can be easily transferred for use with a wide variety of robots and sensor-suites. This framework allows multiple sensors to be developed in parallel as separate application payloads. Moreover, it ultimately enables the end-user to plug and play different payloads for different mission elements. The 5D team envisions three separate payloads each of which can be reconfigured depending on the mission constraints and the hazards to be detected and/or neutralized: 1) subsurface anomaly detection and marking payload, 2) manipulation payload with multiple add-ons for chemical sniffing of complex surfaces as well as dexterous interrogation, and 3) a neutralization payload for neutralizing the hazard.

This talk will discuss implementation strategies employed to integrate these components into a functional system that provides high-performance utility for various real-world tasks. Of particular interest is the cognitive glue, a fuzzy logic rule base, used to sequence and blend these behaviors into challenging mission-level capabilities. Lastly, the paper discusses interface techniques that fuse various forms of robot and world representations and provides a filter to interpret human input and incorporate it seamlessly into the behavioral intelligence of the robotic system.

7664-50, Session 8

Utilizing upconverting phosphors for the detection of TNT

G. P. Glaspell, U.S. Army Corps of Engineers (United States); J. Tabb, Agave BioSystems (United States)

Herein we purpose to utilize upconverting phosphors to detect TNT. Upconverting phosphors possess several advantages for remote sensing applications. Since upconverters are stimulated by the same wavelength of near infrared light (NIR) and are tunable it is possible to detect multiple targets with the same IR source. Also since NIR is used to excite the phosphors auto-fluorescence, typically observed when using an ultra violet (UV) excitation source, from background objects is eliminated increasing the overall sensitivity.

To detect TNT, antibodies specific to TNT are bound to the surface. The role of the antibodies is two fold; to bind a quencher and to accept TNT or DNT. The quencher is chosen so that the luminescence from the phosphor will be absorbed preventing it from emitting, essentially turning off the phosphor off. A diminished phosphor emission would be indicative that the immediate area is free of TNT. However, in the presence of TNT the quencher will be displaced by either TNT or DNT. With the quencher displaced the phosphor will be able to emit light indicating TNT is present in the immediate area.

7664-51, Session 8

Xsense: combining detection methods with nanotechnology for high-sensitivity handheld explosives detectors

A. Boisen, F. G. Bosco, N. Kostesha, J. K. Olsen, M. S. Schmidt, Technical Univ. of Denmark (Denmark)

The demand for fast, portable, reliable, selective and sensitive detection methods for explosives is increasing. Today, explosives are mainly detected by dogs. However, dogs have some limitations such as high training and maintenance costs and require skilled handlers.

In an attempt to address some of these issues the Danish Agency for Science and Technology's, Program Commission on Nanoscience Biotechnology and IT, has issued a $3.850.000 grant to fund the Xsense project (running 2008 to 2012). Four Ph.D. students, three post doctoral researchers in addition to four tenured professors participate in the ongoing research. A close working relationship with the industrial partners Unisensor and SERStech AB has been secured from the project onset.

The key challenges in the future development of sensor based explosives detectors are reliability, selectivity, stability and cost. Our hypothesis is that only by combing several independent and sensitive measuring principles can reliability be improved. Therefore the Xsense project will develop four individual miniaturised sensor technologies (surface enhanced Raman scattering, cantilever-based sensors, calorimetric sensors and colorimetric sensors). Proof of concept has already been established for all four sensor technologies. Using micro- and nanotechnological fabrication techniques the four sensing methods can be combined into a low cost portable device which will be coupled with advanced signal processing and statistical analysis for data output. It is the goal of the Xsense project to provide explosives detection capabilities, otherwise only available to trained dog teams, to personnel with minimal training. Stationary applications are also possible.

7664-52, Session 8

Feasibility of bulk explosives detection using photoneutron spectroscopy

J. E. McFee, A. A. Faust, Defence Research and Development Canada (Canada); K. A. Pastor, McMaster Univ. (Canada)

Research has been conducted since the 1950s on nuclear methods to confirm the presence of bulk explosives by detecting characteristic emitted radiation. In most practical situations, penetrating radiation is required, which restricts the problem to gamma rays and neutrons. The most successful reactions to date has been radiative thermal neutron capture (thermal neutron analysis) and prompt radiative emission following inelastic fast neutron scattering (fast neutron analysis). An alternative to these neutron-in, gamma ray-out reactions is photoneutron production. A gamma ray whose energy exceeds the threshold for neutron production in a particular atomic nucleus can cause a neutron to be emitted. For a given isotope and assuming monoenergetic photons, the emitted neutrons will have a spectrum consisting of one or more discrete energies. If the gamma ray source and neutron spectrometer are appropriately chosen, the neutron spectrum can be used as a fingerprint to identify the isotope. This photoneutron spectroscopy method has a number of potential advantages over thermal and fast neutron analysis, such as generally simpler spectra and low inherent natural neutron background. It also has drawbacks, such as a present lack of suitable fieldable photon sources. This paper will describe the method and preliminary simulations and calculations to examine its feasibility. Possible sources, detectors and geometries will be discussed.

7664-53, Session 8

Advances in standoff detection of trace explosives by infrared photo-thermal imaging

C. A. Kendziora, R. Furstenberg, M. R. Papantonakis, V. Q. Nguyen, U.S. Naval Research Lab. (United States); J. L. Stepnowski, Nova Research, Inc. (United States); B. Hofmann, R. A. McGill, U.S. Naval Research Lab. (United States)

We are developing a technique for the stand-off detection of trace explosives using infrared (IR) photo-thermal imaging. In this approach, compact IR quantum cascade lasers tuned to strong absorption bands in the trace explosives illuminate a surface of interest. An IR focal plane array is used to image the surface and detect any small increase in the thermal emission upon laser illumination. We demonstrate the technique at several meters of stand-off distance indoors and in field tests, while operating the lasers below the eye-safe intensity limit (100 mW/cm2). Sensitivity to explosive traces as small as a single grain (@1 ng) has been demonstrated. By varying the incident wavelength slightly, we show selectivity between TNT and RDX. Using a sequence of lasers at different wavelengths, we increase both sensitivity and selectivity while reducing the false alarm rate. A complete test and analysis can be performed in less than 1 second. We compare results with cooled and uncooled detectors and examine the advantages of fiber delivery of the QCL beams. We are developing a prototype system for outdoor testing at longer stand-off distances. This talk will include an overview of the approach and recent experimental results.

Reference: R. Furstenberg et al. Applied Physics Letters 93, 224103 (2008).

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7664-54, Session 8

Explosives standoff detection using Raman spectroscopy: from bulk toward trace detection

H. Oestmark, A. K. Pettersson, S. Wallin, Swedish Defence Research Agency (Sweden)

Results from standoff detection experiments on explosives using Raman spectroscopy in several types of setups will be presented. Identification capability of bulk amounts within line of sight has been demonstrated up to 470 metes in 1 to 10 seconds using a doubled Nd:YAG laser at 532 nm.

From a user perspective detection capability of trace amounts is essential however and the results of laboratory experiments on explosives in vapor phase will also be presented. These experiments have been made using Resonance Raman Spectroscopy, a variation of spontaneous Raman spectroscopy in which Resonance enhancement is achieved by allowing the Raman laser to approach a molecular resonance in the molecule. The aim of the experiments so far has been to measure the resonance enhancements rather than demonstrating the actual standoff capability. Resonance enhancements of up to 10Exp5 have been achieved for 2,4-DNT.

Efforts on Raman particle detection have also been successfully undertaken, and the results from these experiments are presented and future improvements discussed. Target substances in this case include TNT, DNT and Ammonium Nitrate.

7664-56, Session 8

Fusing chlorophyll fluorescence and plant canopy reflectance to detect TNT contamination in soils

D. R. Young, Virginia Commonwealth Univ. (United States); J. C. Naumann, U.S. Army Corps of Engineers (United States)

TNT is released into the soil from many different sources, especially from military and mining activities, including buried land mines. Vegetation may absorb explosive residuals, causing stress and by understanding how plants respond to energetic compounds, we may be able to develop non-invasive techniques to detect soil contamination. The objectives of our study were to examine the physiological response of plants grown in TNT contaminated soils and to use remote sensing methods to detect uptake in plant leaves and canopies in both laboratory and field studies.

Differences in physiology and light-adapted fluorescence were apparent in laboratory plants grown in TNT contaminated soils, prior to visible signs of stress. Several reflectance indices were able to detect TNT contamination including the Photochemical Reflectance Index (PRI), R740/R850 and R735/R850, which may be attributed to transformation and conjugation of TNT metabolites with other compounds. Field studies at the Duck, NC Field Research Facility revealed differences in physiological stress measures, and leaf and canopy reflectance when plants growing over suspected buried UXOs were compared with reference plants. Multiple reflectance indices indicated stress at the suspected contaminated sites, including R740/R850 and R735/R850 and there were significant differences in the Normalized Difference Nitrogen Index.

Under natural conditions of constant leaching of TNT into the soil, TNT uptake would be continuous in plants, potentially creating a distinct signature from remotely sensed vegetation. We may be able to use remote sensing of plant canopies to detect TNT soil contamination prior to visible signs.

7664-57, Session 8

Standoff detection of obscured threats while on the move

P. J. Treado, M. P. Nelson, R. Schweitzer, P. Feineigle, P. Mangold, C. Anderson, R. Rodgers, ChemImage Corp. (United States)

Short wave infrared (SWIR) hyperspectral imaging sensors for standoff hazardous materials detection are showing promise. Detection of surface and sub-surface hazards is accomplished by exploiting measurable optical phenomena with hyperspectral imaging sensor designs that can be made to operate while on the move (OTM). This presentation will emphasize strategies being employed for sensor exploitation.

7664-58, Session 8

Liquid explosives detection in transparent containers

M. L. Gaft, Laser Detect Systems, Ltd. (Israel)

Evaluation of the possibility to detect liquid explosives in transparent containers using gated Raman technique.

7664-91, Session 8

High-resolution soil moisture mapping using operational optical satellite imagery

J. M. H. Hendrickx, B. J. Harrison, B. Borchers, G. Rodríguez Marín, New Mexico Institute of Mining and Technology (United States); S. Howington, U.S. Army Engineer Research and Development Ctr. (United States); J. R. Ballard, Jr., U.S. Army Corps of Engineers (United States)

Soil moisture conditions have an impact upon virtually all aspects of Army activities and are increasingly affecting its systems and operations. Soil moisture conditions affect operational mobility, detection of landmines and unexploded ordinance, natural material penetration/excavation, military engineering activities, blowing dust and sand, watershed responses, and flooding. This study explores a novel method for high-resolution (2.7 m) soil moisture mapping using remote satellite optical imagery that is readily available from Landsat and QuickBird. The soil moisture estimations are needed for the evaluation of IED sensors using the Countermine Simulation Testbed in regions where access is impossible or difficult. The novel method has been tested in Helmand Province, Afghanistan, using a Landsat7 image and a QuickBird image of April 23 and 24, 2009, respectively. The first implementation of the novel method yielded promising results as will be reported.

7664-59, Session 9

Evaluation test of ALIS in Cambodia for humanitarian demining

M. Sato IV, Tohoku Univ. (Japan)

Since 2002, we have developed a new hand-held land mine detection dual-sensor ALIS. ALIS is equipped with a metal detector and a GPR, and it has a sensor tracking system, which can record the GPR and Metal detector signal with its location. ALIS can process the data and is used for image re-construction by migration processing. ALIS is the only one mine detection system in the world which can visualize the GPR image by hand scanning. We found that the migration processing can reduce the clutter and gives us clear images of buried mines. After several tests of ALIS in mine affected courtiers, a long-term evaluation test in real mine fields has started in Croatia in winter 2008. Then, operation of ALIS in mine fields in Cambodia started in summer 2009. Two sets of ALIS have been operated in Cambodia and more than 30 antipersonnel mines have been detected.

7664-60, Session 9

Development of dual-sensor handheld detector

M. Sezgin, TÜBITAK (Turkey)

Buried object detection is an important issue for underground inspection. Target object may be metallic or non-metallic. Metallic object detection can be performed by EMI (Metal) sensor, but non-metallic objects can not be detected by this sensor. For this case extra sensor is needed. GPR (Ground Penetrating Radar) was selected as additional sensor for this

purpose.

In this study we present a dual sensor hand held detector for both metallic and non metallic buried object detection purpose. The proposed ergonomical system has also buried object identification capability.

7664-61, Session 9

Fusion techniques for hybrid ground-penetrating radar: electromagnetic induction landmine detection systems

M. Laffin, M. Mohamed, A. Etebari, M. W. Hibbard, NIITEK, Inc. (United States)

Hybrid ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors have advanced landmine detection far beyond the capabilities of a single sensing modality. Both probability of detection (Pd) and false alarm rate (FAR) are impacted by the algorithms utilized by each sensing mode and the manner in which the information is fused. Algorithm development and fusion will be discussed, with an aim at achieving a threshold probability of detection (Pd) of 0.98 with a low false alarm rate (FAR) of less than 1 false alarm per 2 square meters. Stochastic evaluation of prescreeners and classifiers is presented with subdivisions determined based on mine type, metal content, and depth. Training and testing of an optimal prescreener on lanes that contain mostly low metal anti-personnel mines is presented. Several fusion operators for prescreeners and classifiers, including confidence map multiplication and support vector machine, will be investigated and discussed for integration into our algorithm architecture.

7664-62, Session 9

Fusion of ground-penetrating radar and electromagnetic induction sensors for landmine detection and discrimination

M. P. Kolba, Signal Innovations Group, Inc. (United States); P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors provide complementary capabilities in detecting buried targets such as landmines, suggesting that the fusion of GPR and EMI modalities may provide improved detection performance over that obtained using only a single modality. This paper considers both pre-screening and the discrimination of landmines from non-landmine objects using real landmine data collected from a U.S. government test site as part of the Autonomous Mine Detection System (AMDS) landmine program. GPR and EMI pre-screeners are first reviewed and then a fusion pre-screener is presented that combines the GPR and EMI pre-screeners using a distance-based likelihood ratio test (DLRT) classifier to produce a fused confidence for each pre-screener alarm. The fused pre-screener is demonstrated to provide substantially improved performance over the individual GPR and EMI pre-screeners.

The discrimination of landmines from non-landmine objects using feature-based classifiers is also considered. The GPR feature utilized is a pre-processed, spatially filtered normalized energy metric. Features used for the EMI sensor include model-based features generated from the AETC model and a dipole model as well as features from a matched subspace detector. The EMI and GPR features are then fused using a random forest classifier. The fused classifier performance is superior to the performance of classifiers using GPR or EMI features alone, again indicating that performance improvements may be obtained through the fusion of GPR and EMI sensors. The performance improvements obtained both for pre-screening and for discrimination have been verified by blind test results scored by an independent U.S. government contractor.

7664-63, Session 9

Feature extraction and object recognition in multimodal forward-looking imagery across sensor platforms

J. M. Keller, Univ. of Missouri-Columbia (United States); G. Greenwood, M. Bradfield, Portland State Univ. (United States); D. G. Schartman, B. Calhoun, Univ. of Missouri-Columbia (United States); T. T. Ton, D. C. Wong, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Univ. at Buffalo (United States)

The U. S. Army Night Vision and Electronic Sensors Directorate (NVESD) recently tested an explosive-hazards detection vehicle which combines a pulsed FLGPR with a visible-spectrum color camera. Additionally, NVESD tested a human-in-the-loop multi-camera system with the same goal in mind. It contains wide field-of-view color and infrared cameras as well as zoomable narrow field-of-view versions of those modalities. Even though they are separate vehicles, having information from both systems offers great potential for information fusion. Based on previous work at the University of Missouri, we are not only able to register the UTM-based positions of the FLGPR to the color image sequences on the first system, but we can register these locations to corresponding image frames of all sensors on the human-in-the-loop platform. This paper presents our approach to first generate libraries of multi-sensor information across these platforms. Subsequently, research is performed into feature extraction and recognition algorithms based on the multi-sensor signatures. Our goal is to tailor specific algorithms to recognize and eliminate different categories of clutter and to be able to identify particular explosive hazards.

We demonstrate our library creation, feature extraction and object recognition results on a large data collection at a US Army test site.

7664-64, Session 9

Improved detection and false alarm rejection using FLGPR and color imagery in a forward-looking system

T. C. Havens, C. J. Spain, D. K. Ho, J. M. Keller, Univ. of Missouri-Columbia (United States); T. T. Ton, D. C. Wong, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Univ. at Buffalo (United States)

Forward-looking ground-penetrating radar (FLGPR) has received a significant amount of attention for use in explosive-hazards detection. A drawback to FLGPR is that it is sensitive to not only explosive-hazards but also to clutter objects, which results in an excessive number of false detections. This paper presents our analysis of the explosive-hazards detection system tested by the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD). The NVESD system combines a pulsed FLGPR with a visible-spectrum color camera. We present an FLGPR target detection algorithm that uses a locally-adaptive detection scheme with shape-based features. The FLGPR target detections are then projected into the camera imagery and image-based features are collected for each detection. A Mahalanobis-metric classifier is then used to reduce the number of false detections. We show that our proposed FLGPR target detection algorithm, coupled with our camera-based false alarm reduction method, is effective at reducing the number of false alarms in test data collected at a US Army test facility.

7664-65, Session 9

Quantifying the benefit of airborne and ground sensor fusion for target detection

M. Silvious, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

In this paper, a study involving detecting buried objects by fusing airborne Multi-Spectral Imaging (MSI) and ground-based Ground Penetrating Radar (GPR) sensors is reported on. The benefit of using the airborne sensor to cue the GPR, which will then search the area indicated by the MSI, is investigated and compared to results obtained via a purely ground-based system. State-of-the-art existing algorithms, such as hidden Markov models, Edge Histogram Descriptors with Relevance Vector Machines, and Spectral features will be applied to the GPR data both in queued and non-queued mode. In addition, the ability to measure disturbed earth with the GPR sensor will be investigated. Furthermore, state-of-the-art algorithms for MSI system will be described. These algorithms require very high detection rates with acceptable false alarm rates in order to serve as a acceptable system. Results will be presented on data collected at outdoor testing and evaluation sites.

7664-66, Session 9

Dual-sensor platforms for UXO detection using GPR and EMI

J. A. Marble, U.S. Army Night Vision & Electronic Sensors Directorate (United States); K. Hong, Defence Science and Technology Organisation (Australia)

Nemesis is a platform developed by Applied Research Associates for detection of landmines and landmine-like in-road objects. The system incorporates a ground penetrating radar array and a metal detector array. These two sensors are used in conjunction to detect and classify objects of interest. In this paper three fusion algorithms are explored. First, detections are made by ANDing the data together. This produces a detection list with a reduced false alarm rate. However, the probability of detection is often reduced with this approach because both sensors must detect the object. Some landmine like objects are, therefore, eliminated because they are not jointly detected. The second algorithm fuses the two sensor data sets by ORing their detections. This allows for the highest probability of detection since it keeps the alarms of both sensors. However, this second approach also has the highest false alarm rate. The third algorithm is an advanced approach that provides greater false alarm rejection without significantly impacting probability of detection. This algorithm is described and its performance trade-offs are discussed. ROC curves are used to quantify the performance of the fusion algorithms. Curves are presented for each sensor standing alone and for each fusion algorithm.

7664-67, Session 10

Carrier tracking and tunable pass band filters for forward-looking TDM-LDV mine detection

R. D. Burgett, J. M. Sabatier, V. Aranchuk, The Univ. of Mississippi (United States)

Using laser Doppler vibrometers (LDV) to find buried land mines has been shown to have a high probability of detection coupled with a low probability of false alarms. Equally good results have been achieved using a 16-beam LDV. Time division multiplexing (TDM) of this multiple-beam LDV has also been investigated as a means of increasing the scanning speed and potentially allowing the sensor to move down the road at speeds faster than that allowed using stop-and-stare LDV. A moving platform induces Doppler shifts in the LDV beams that are not perpendicular to the motion vector. This shift can be much greater than the modulation bandwidth of a stationary LDV signal; therefore, the demodulation must allow for the shift either by increasing the processing bandwidth, which increases the system noise or by tracking the Doppler offset and adjusting a band pass filter's center frequency. A method has been developed to track the carrier frequency to compensate for the Doppler offset for each of the 16 channels caused by the moving platform and adjusting the center frequency of a digital band pass filter. This paper will present the basic filter structure and compare the noise statistics from two different carrier tracking methods that were investigated.

7664-68, Session 10

Outdoor synthetic aperture acoustic ground target measurements

S. S. Bishop, U.S. Army Night Vision & Electronic Sensors Directorate (United States); T. Ngaya, J. F. Vignola, J. A. Judge, The Catholic Univ. of America (United States); J. A. Marble, P. M. Gugino, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Univ. at Buffalo (United States)

A novel outdoor synthetic aperture acoustic (SAA) system is mounted on a 6.1 meter rail system. This is an extension from a prior indoor laboratory measurement system where selected targets where ensonified while suspended in air [1]. Here the measurement system is designed and constructed to collect data while mounted on a rail-like system ensonifying the perpendicular to its direction of travel. Ground surfaces consisted of weathered asphalt and short grass. Several surface-laid objects were arranged on the ground for SAA imaging. These included rocks, concrete masonry blocks, grout covered foam blocks; foliage obscured objects and several spherical canonical targets such as a bowling ball, plastic and metallic balls. The synthetic scene is processed and ground targets are further analyzed for characteristics and features amenable for discriminating. Reported is a description of the measurement system, target descriptions, synthetic aperture processing approach and preliminary findings with respect to ground surface and target characteristics.

7664-69, Session 10

Comparison of robot localization techniques in absence of GPS

R. Vincent, SRI International (United States)

GPS is the quick and easy solution to localize an outdoor robot. However when a GPS is not available (like indoors) or not reliable enough, we have developed, at SRI International, other techniques that replace the GPS.

Without GPS, the robot is outfitted with some others sensors to help it get localized. The best sensors to replace a GPS are either a laser range finder or a camera.

Laser range finders are far more precise and easier to work with than cameras.However they are only 2D sensors, so you only going to get localized in 2D.

The main class of localization algorithms that uses a laser is called a SLAM (simultaneous localization and mapping) system. There are many different implementations of a SLAM system from open-source ones to commercial versions. Our SLAM system has an RMS error in XY of 0.1%.

Unless you have powerful lights on your robot or you can guarantee constant lighting, cameras are not reliable enough indoor. Outdoor, on the other hand, cameras and especially a pair of cameras are an effective solution to localize your robot. In recent years, 3D Visual Odometer algorithms using camera data to achieve localization have been developed. Our own visual odometer has a RMS error in XYZ of 0.49% [1].

In this paper, we will compare the different solutions we have to localize a robot without GPS, either indoor or outdoor.

[1] K. Konolige, M. Agrawal, and J. Sola. Large scale visual odometry for

rough terrain. In Proc. International Symposium on Research in Robotics (ISRR), November 2007.

7664-70, Session 11

Development of an integrated soils laboratory for modeling and detection applications

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The Geotechnical and Structures Laboratory at the US Army Corps of Engineers is developing a near-surface properties laboratory that will provide complete characterization of soil. Data from this laboratory will be incorporated into a comprehensive database, to enhance military force projection by providing physical properties for modelers and designers of imaging and detection systems, and will allow for the cross-referencing of mineralogical, electromagnetic, thermal, and optical properties to predict surface and subsurface conditions. We will present an example data set from recent collection efforts including FTIR in the Near-IR, MWIR, and LWIR bands, magnetic susceptibility (500 Hz to 8 GHz), and soil conductivity and complex permittivity (10 μHz to 8GHz) measurements. X-ray fluorescence data and chemical composition will be presented along with a discussion of site geology, sample collection, preparation method, and mineralogy. This type of data-collection effort provides useful constraint information of soil properties for use in modeling and target detection. By establishing real ranges for critical soil properties, we are able to improve algorithms to define anomalies that can indicate the presence of land mines, UXO, IEDs, tunnels, and other visually obscured threats.

7664-71, Session 11

Common IED exploitation target set ontology

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The Common IED Exploitation Target Set (CIEDETS) ontology provides a comprehensive semantic data model for capturing knowledge about sensors, platforms, missions, environments, and other aspects of systems under test. The CIEDETS ontology also includes representative IEDs, modeled as a variety of explosives, camouflage, concealment objects, and other background objects, which comprise an overall threat scene. Background objects include disturbed soil and associated signatures, both broadband and spectral.

The CIEDETS ontology has been created using the Web Ontology Language (OWL) and the SPARQL Protocol and RDF Query Language, which ensures portability of the captured knowledge across applications. The resulting knowledge base is a component of the Web-enabled CIEDETS application, which is intended to support the end-user sensor test and evaluation community. CIEDETS associates a system under test, including the specification of its sensors, platform, mission, and operating environment to a subset of cataloged threats based on the probability that the system under test will detect the threat. The associations between systems under test and threats are established based on a novel hybrid reasoning strategy that applies a combination of heuristics and simplified modeling and simulation techniques. The CIEDETS ontology is useful for many purposes, including supporting the Web-enabled application that eliminates unnecessary test configurations for a given system under test and threat scenarios. However, the ontology has captured knowledge in an application independent manner such that it can be leveraged in a myriad of applications, including serving as a knowledge source for mission planning tools.

7664-72, Session 11

Detection of shallow buried nonmetallic landmines in microwave X-band region using multipolarisation data

K. C. Tiwari, Indian Defence Services (India); D. Tiwari, M. K. Arora, Indian Institute of Technology Roorkee (India)

Alternative approaches and models continue to be investigated and evolved to correctly locate and identify a buried mine with minimum risk. Though microwave remote sensing based detection of shallow buried landmines provides such a risk free alternative, but it is a highly complex and computationally intensive task involving several parameters. The present paper deals with the use of data obtained in multiple polarizations and their transforms approximating smooth roughness conditions in sand for landmine detection. Data in both HH and VV polarizations in microwave X-band frequency (10 GHz, 3cm) was generated using dummy landmines (without explosives) for the present study under laboratory conditions. Various transforms such as image differencing, image ratioing and polarization discriminant ratio (PDR) were studied for its effect on landmine detection. However, it was found that most of the clutter and noise gets suppressed on using a transform obtained by subtracting the difference of data in two polarizations from its sum. The surface roughness conditions was approximated as smooth as available in western parts of India. These conditions make them extremely suitable for application of microwave radar remote sensing for detection of minefields. With the advent of satellites providing data in various polarizations, it has now become relevant to investigate methods which can be used for landmine detection using polarization techniques. The proposed analysis is expected to be extremely useful in future in detection of landmines using multi-polarisation satellite data in microwave X-band in deserts such as those existing in the western borders of India.

7664-73, Session 11

Development of x-ray and gamma-ray CZT detectors for homeland security applications

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Cadmium Zinc Telluride (CZT) continues to progress in quality and cost as a detector material for hard X-ray and gamma-ray photons. We have produced 2 x 2 x 1cm3 CZT detectors with alternative anode and cathode designs in an effort to maintain the excellent detection efficiency, energy resolution, and spatial localization achieved with pixellated CZT detectors while reducing the number of readout channels. For different contact patterns, we study the effects of the 3-D location of interaction on the detected signals using a highly collimated beam of x-rays. We also investigate the effectiveness of different insulating materials in reducing leakage currents between steering and readout contacts, a major contributor to detector noise and performance in CZT detectors.

7664-74, Session 12

Automatic forest canopy removal algorithm for underneath obscure target detection by airborne lidar point cloud data

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ISPRS Working Group III/3 conducted a test and found that all bare ground point extraction filter algorithms perform well on LiDAR point clouds from smooth rural landscapes, but all produce errors in rough terrain with vegetation. This study develops a novel algorithm to help detecting obscure targets underneath forest canopy and mitigate the vegetation problem for those filters as well. In this proposed work, the multiple-return characteristic of LiDAR data is analyzed and accordingly laser shots are classified as single-return or multiple-return shots. The challenge of removing canopy is that some foliage will reflect unexpectedly single-return shots rather than normal multiple-return shots when they are very dense. This challenge is solved using our-developed algorithms such as analyzing distance relationships between foliage, applying morphological filters to process the canopy/non-canopy image and creating rough digital terrain model to calculate above ground levels of points, etc. The unique feature of our approach is that no parameter tweaking is required. The results are obtained by processing actual LiDAR data collected in the Hogtown area near UF campus and it shows that all forest canopy points have been removed and all obscure vehicles or buildings underneath canopy can now be easily seen. Besides, the occluded rate of forest canopy can be easily obtained by our canopy removal algorithm. For military application, thermal imaging cameras can see the heat signature of people, boats, and vehicles in total darkness as well as through smoke, haze, and light fog, but not through the forest canopy unlike our algorithm.

7664-75, Session 12

Forward-looking anomaly detection via fusion of infrared and color imagery

K. E. Stone, J. M. Keller, M. Popescu, T. C. Havens, D. K. Ho, Univ. of Missouri-Columbia (United States)

This paper develops algorithms for the detection of interesting and abnormal objects in color and infrared imagery taken from cameras mounted on a moving vehicle, observing a fixed scene. The primary purpose of detection is to cue a human-in-the-loop detection system. Algorithms for direct detection and change detection are investigated, as well as fusion of the two. Both methods use temporal information to reduce the number of false alarms.

The direct detection algorithm uses image self-similarity computed between local neighborhoods to determine interesting, or unique, parts of an image. Neighborhood similarity is computed using Euclidean distance in CIELAB color space for the color imagery, and Euclidean distance between grey levels in the infrared imagery. The change detection algorithm uses the affine scale-invariant feature transform (ASIFT) to transform multiple background frames into the current image space. Each transformed image is then compared to the current image, and the multiple outputs are fused to produce a single difference image. Changes in lighting and contrast between the background run and the current run are adjusted for in both color and infrared imagery. Frame-to-frame motion is modeled using a perspective transformation, the parameters of which are computed using scale-invariant feature transform (SIFT) keypoint correspondences. This information is used to perform temporal accumulation of single frame detections for both the direct detection and change detection algorithms. Performance of the proposed algorithms is evaluated on multiple lanes from a data collection at a US Army test site.

7664-76, Session 12

Exploiting spatial distributions for patterned and scatterable minefield detection in cluttered environment

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Spectral, shape or texture features of the detected targets are used to model the likelihood of the detections to be potential mines in a minefield. However, a large number of these potential mines can be

false alarms due to the similarity of the mine signatures with natural and other manmade clutter signatures which significantly affects the overall detection performance. However, in addition to the target features, spatial distribution of the detected targets can be used to improve the minefield detection performance. In this paper, target features and target spatial distributions are implemented simultaneously for both patterned and scatterable minefields. We use nearest neighbor distances of the detected targets to capture the spatial distribution. Target spatial distributions for patterned minefields containing one, two and three mine rows are not too difficult to explore since mine sizes are usually large and distinguishable, and these mines normally follow a distinct linear pattern. On the other hand, mines in scatterable minefields are generally small in size, mine features are not often easily distinguishable from false alarm features, and spatial distributions of mines may not be very different from false alarms. Therefore, exploiting spatial distributions of scatterable mines is not trivial. We will investigate the spatial distributions and evaluate minefield performance for both patterned and scatterable minefields in a cluttered environment where the number of detected mines is much smaller than the number of false alarms. For patterned minefields, minefield performance of single, double, and triple mine rows at different mine level probabilities of detection will be evaluated. For scatterable minefields, we will evaluate the performance of minefields where potential mines are spatially randomly or regularly distributed. In all cases, the false alarms are assumed to be spatially randomly distributed. The performance of the proposed detection algorithms is compared to the baseline algorithms using extensive simulated minefield data.

7664-77, Session 12

GPU-based processing for airborne detection

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Onboard real time processing is highly desirable in airborne detection applications. Since the data processing involved in detection using electro-optical sensors is computationally expensive, typically a high power multi-rack system is required to achieve real time detection. Use of such hardware is often not feasible in an airborne application due to space and power constraints. Recently there has been a lot of interest in the use of FPGAs and GPUs for real time image processing because of their highly parallel architecture, low cost, and compact size. While FPGAs have lower latencies and offer customizable pipelined architecture to suit the data flow of the application, they suffer from lower clock frequency and smaller on-chip memory as compared to commercial off-the-shelf GPUs. GPUs also enjoy ease of programming using high level languages like C/CUDA (Nvidia), CTM(ATI), OpenCL, etc., thus having potentially lower development cost. In this paper different available computational architectures are reviewed and their performance in terms of computation speed, watts/GFLOPS, and weight/GFLOPS are evaluated. GPU implementations of image unwarping, band to band registration, image registration, multiband RX anomaly detector, and diffusion based edge detection are presented. Execution times are compared for these algorithms implemented in Matlab on CPU, C++/Intel Integrated performance Primitives (IPP) on CPU and C/CUDA on GPU. We also identify the sub-problems within airborne detection that can be efficiently parallelized on the SIMD architecture of the GPU.

Key Words: airborne detection, GP-GPU, CUDA, IPP, Image registration, RX anomaly detector, band to band registration, diffusion, edge detection.

7664-78, Session 12

Multiple instance learning for landmine detection in ground-penetrating radar data

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The use of vehicle mounted ground penetrating radar systems provides a data cube of electro-magnetic responses of volumes below the surface.

For the purposes of detection, features are then extracted from this data cube and are use to determine if there is a target present or not. Feature extraction and selection is an area of great interest for algorithm developers as algorithms use this information to determine if a target is present.

Edge Histogram Descriptors (EHD) have been previously computed for landmine detection (Frigui et al). EHD features have been successfully used by detection algorithms, scoring high probability of detections (PDs) at low false alarm rates (FARs) (Frigui et al).

There are training, or learning, issues when developing a detection algorithm for GPR images since the signature is somewhat diffuse, difficult to precisely locate, and only resides in a subset of an image. Currently for training of the EHD classifier, human intervention is required to identify the depth at which only the landmine signature is apparent. In this manner the EHD algorithm is able to learn features associated with landmine signatures and not the background or noise features of a training image.

Multiple Instance Learning (MIL) is a newly formalized machine learning paradigm which provides explicit mechanisms for learning in the presence of noise. In MIL, a learner is presented with sets of samples; whereas in standard techniques, a learner is presented with individual samples. In the following, a random set framework for multiple instance learning (RSF-MIL) is developed which can directly and more succinctly perform analysis on sets. This natural framework for MIL provides for a more general solution and a more versatile learning tool.

MIL techniques fit the learning problem associated with GPR data since only some subset of the data actually contains a landmine signature, whereas the majority of the data is filled with background and noise. Furthermore, this approach does not require human intervention during the learning process.

Experimental results show that RSF-MIL can learn intuitive features that indicate the presence of a subsurface target. This information is then used for the identification and detection of subsurface targets using an extensive GPR dataset. Detection results are comparable to the existing state-of-the-art, with the added benefits accompanying MIL approaches.

7664-79, Session 12

Information-based sensor management for the intelligent tasking of ground-penetrating radar and electromagnetic induction sensors in landmine detection prescreening

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Previous work has introduced a framework for information-based sensor management that is capable of tasking multiple sensors searching for targets among a set of discrete objects or in a cell grid. However, in many real-world scenarios-such as detecting landmines along a lane or road-an unknown number of targets are present in a continuous spatial region of interest. Consequently, this paper introduces a grid-free sensor management approach that allows multiple sensors to be managed in a sequential search for targets in a grid-free spatial region. Simple yet expressive Gaussian target models are introduced to model the spatial target responses that are observed by the sensors. The sensor manager is then formulated using a Bayesian approach, and sensors are directed to make new observations that maximize the expected information gain between the posterior density on the target parameters after a new observation and the current posterior target parameter density. The grid-free sensor manager is applied to a set of real landmine detection data collected with ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors at a U.S. government test site. Results are presented that compare the performance of the sensor manager with the performance of an unmanaged joint pre-screener that fuses individual GPR and EMI pre-screeners. The sensor manager is demonstrated to provide improved detection performance while requiring substantially fewer sensor observations than are made with the unmanaged joint pre-screening approach.

7664-80, Session 13

Effect of radar undesirable characteristics on the performance of spectral feature landmine detection technique

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Two factors that affect the performance of ground penetrating radar for landmine detection are ground bounce and self-signature. Ground bounce is caused by the strong radar reflection from the ground surface and its effect can be minimized through range gating. The radar self-signature is created by the internal coupling of the radar itself and it appears as constant value in different scans. Although not varying much, the radar self-signature can create hyperbolic shape after ground alignment and thereby increasing the amount of false detections.

Radar self-signature is not a main factor that affects detection performance in previous generation of GPR. This is because it has a high noise floor and the self-signature is buried in noise. In the newer generation of GPR, the noise floor is much lower and the self-signature becomes very obvious in the GPR signal return. The self-signature causes an increase in false alarm rate from a pre-screener detection algorithm and could lead to performance degradation of a feature based algorithm. This paper focuses on the effect of radar self-signature on the performance of the subspace spectral feature landmine detection algorithm.

Based on the data collected at a government test site, initial results indicate that the spectral feature landmine detection algorithm does not appear to be sensitive to the presence of self-signature in the data. Indeed, better results are obtained from the new generation of GPR due to its reduction of noise floor. Investigation of radar self-signature on spectral based detector will be examined in the paper, together with comparison and fusion with other landmine detection algorithms including Hidden Markov Model (HMM) and Edge Histogram Descriptor (EHD).

7664-81, Session 13

Anomaly detection in forward-looking infrared imaging using one-class classifiers

M. Popescu, K. E. Stone, T. C. Havens, J. M. Keller, D. K. Ho, Univ. of Missouri-Columbia (United States)

In this paper we describe a method for generating cues of abnormal objects present in the field-of-view of an infrared (IR) camera installed on a moving vehicle. The proposed method has two steps. First, for each frame we generate a set of possible points of interest using a corner detection algorithm. Second, the points related to the background are discarded using a one class classifier (OCC) trained on features extracted from a local neighborhood around each point.

The advantage of using an OCC is that we do not need examples from the abnormal object class to train the classifier. Instead, the OCC is trained using corner points from images known to be free of abnormal objects, i.e., that contain only background scenes. To further reduce the number of false alarms we use a temporal fusion procedure; a region has to be detected in m out of n, m<n, consecutive frames to be reported as abnormal.

To choose the best classifier for our task, we compare the performance of three OCCs: nearest neighbor (NN), support data description (SDD), and Gaussian mixture (GM). The comparison is performed using a set of about 900 background point neighborhoods for training and 400 for testing. The best performing OCC is then used to detect abnormal objects in a set of IR video sequences obtained on a 1 mile long country road at a US Army test site.

7664-82, Session 13

Depth estimation of buried objects using wavelet transform and statistical hypothesis testing

A. B. Yoldemir, M. Sezgin, TÜBITAK (Turkey)

Identification of buried objects is an important issue of underground inspection. After the detection of suspicious region, the target is localized and identification process is accomplished. Due the nature of the problem, signature of a big target at a certain depth may give equivalent information to the signature of a smaller target at shallower depth, unless depth information is not used. So, depth information is coming into prominence in classification step to increase the identification performance.

In this study, we propose a burial depth estimation method over GPR data. In our work, discrete wavelet transform is used in the preprocessing step. This step consists of getting rid of the ground bounce and other redundancies in the GPR return signal. After this stage, statistical hypothesis tests -which point out the likelihood of an assumption made about a sample-, are utilized to detect the statistical discrepancies in the returning signals at different depth levels. These tests are also beneficial for locating smooth regions of the returning signal with a predetermined significance level, which may be filtered out, as these regions most probably do not include a target. We will be presenting our test results on an extensive data set consisting of different targets buried in different types of soil.

7664-83, Session 13

Detection of IEDs using the GPR only portion of the HSTAMIDS system

J. Tabony, D. O. Carlson, H. A. Duvoisin III, L-3 CyTerra (United States)

The legacy AN/PSS-14 Handheld Mine Detecting Set (also called HSTAMIDS for Handheld Standoff Mine Detection System) has proven itself over the last 7 years as the state-of-the-art in land mine detection, both for the US Army and for Humanitarian Demining groups such as HALO. Its dual sensor GPR (Ground Penetrating Radar) and MD (Metal Detection) have provided receiver operating characteristic curves (Pd versus FAR) that routinely set the mark for such devices. Since its inception and type-classification in 2003 as the US Army standard, the desire for use of the AN/PSS-14 against alternate treats - such as Improvised Explosive devices or IEDs - has recently become paramount. To this end, L-3 CyTerra has developed and tested IED detection and discrimination algorithms using only the SFCW GPR portion of the system, versus the fused version that is used to optimally detect land mines. Performance of the new IED algorithm against representative zero-metal IED target and clutter emplacements is depicted, with the utility to the operator also described.

7664-84, Session 13

Locally adaptive detection algorithm for forward-looking ground-penetrating radar

T. C. Havens, D. K. Ho, J. M. Keller, M. Popescu, Univ. of Missouri-Columbia (United States); T. T. Ton, D. C. Wong, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Soumekh, Univ. at Buffalo (United States)

This paper proposes an effective anomaly detection algorithm for the forward-looking ground penetrating radar (FLGPR) developed by the Army Night Vision and Electronics Sensors Directorate. The forward-looking radar is a pulsed radar and covers a frequency range from 0.5 to 2 GHz.

One challenge for threat detection using FLGPR is its high dynamic range in response to different kinds of targets and clutter objects. The application of a fixed threshold to the post-processed and beamformed FLGPR data for detection often yields a large number of false alarms because the energy returns of some targets are relatively weak. We propose a locally adaptive detection method that adjusts the detection criteria automatically and dynamically across different spatial regions which improves the detection of weak scattering targets.

The paper also examines the improvement in target detection when performing beamforming over different frequency ranges. The detection performance increases by accounting for the distinct frequency response characteristics between threat targets and clutter objects. Experimental results for the improved detection techniques are demonstrated by field data measurements from a US Army test site.

7664-85, Session 14

Preprocessing of GPR data for syntactic landmine detection and classification

A. O. Nasif, K. J. Hintz, N. Peixoto, George Mason Univ. (United States)

Syntactic pattern recognition is being used to detect and classify non-metallic landmines in terms of their spatial impedance discontinuity profile. This profile, extracted from the ground penetrating radar's return signal, constitutes a high-range-resolution and unique description of the inner structure of a landmine. In this paper, we discuss three preprocessing steps necessary to extract such a profile, namely, inverse filtering (deconvolving), binarization, and denoising. We validate the use of an inverse filter to effectively decompose the observed composite signal resulting from the different layers of dielectric materials of a landmine. It is demonstrated that the transmitted radar waveform undergoing multiple reflections with different materials does not change appreciably, and mainly depends on the transmit and receive processing chains of the particular radar being used. Then, a new inversion approach for the inverse filter is presented based on the cumulative contribution of the different frequency components to the original Fourier spectrum. We discuss the trade-offs and challenges involved in such a filter design. The purpose of the binarization scheme is to localize the impedance discontinuities, by assigning a '1' to the peaks of the inverse filtered output, and '0' to all other values. The presence of noise can change the locations of these peaks or introduce spurious peaks. So, appropriate noise filtering should be performed both before and after the inverse filtering. We discuss a simple denoising approach using Haar transformations. The paper is concluded with simulation results showing the effectiveness of the proposed preprocessing techniques.

7664-86, Session 14

Upper bound on false alarm rate for landmine detection and classification using syntactic pattern recognition

A. O. Nasif, B. L. Mark, K. J. Hintz, N. Peixoto, George Mason Univ. (United States)

Recently, there has been considerable interest in the development of robust, cost-effective and high performance non-metallic landmine detection systems using ground penetrating radars (GPR). Many of the available solutions try to discriminate landmines from clutter by extracting some form of statistical or geometrical information from the raw GPR data, and often times, it is difficult to assess the performance of such systems without performing extensive field experiments. In our approach, a landmine is characterized by a binary string corresponding to its impedance discontinuity profile, which can be detected very quickly by syntactic pattern recognition implemented by finite state machines. Such an approach is expected to be very robust in terms of detection and false alarm probabilities, since it exploits the inner structure of a landmine by appropriately preprocessing the raw GPR signal. In this

paper, for our scheme we develop a method to calculate an upper bound on the false alarm rate (FAR), which is defined as the probability of false alarm per unit area. First, we parameterize the number of possible mine patterns in terms of the number of impedance discontinuities, dither and noise. Then, a combinatorial enumeration technique is used to quantify the number of admissible strings. The upper bound on FAR is given as the ratio of the number of possible mine pattern strings to the number of admissible strings per unit area. The numerical results show that the upper bound is smaller than the FAR reported in the literature for a wide range of parameter choices.

7664-87, Session 14

Non-parametric Bayesian time-series modeling and clustering of time-domain ground penetrating radar landmine responses

K. D. Morton, Jr., P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Time Domain Ground penetrating radar (GPR) has been shown to be a powerful sensing phenomenology for detecting buried objects such as landmines. Landmine detection algorithms operating on GPR data typically utilize a feature-based pattern classification algorithm to discriminate buried landmines from other sub-surface objects. In high-fidelity GPR, the time-frequency characteristics of a landmine response should be indicative of the physical construction and material composition of the landmine and could therefore be useful for discrimination from other non-threatening sub-surface objects. In this research we propose the modeling of landmine time-domain responses with a non-parametric Bayesian time-series model and we perform clustering of these time-series models with a hierarchical non-parametric Bayesian model. Each time-series is model as a hidden Markov model (HMM) with autoregressive (AR) state densities. The proposed non-parametric Bayesian prior allows for automated learning of the number of states in the HMM as well as the AR order within each state density. This creates a flexible time-series model with complexity determined by the data. Furthermore, a hierarchical non-parametric Bayesian prior is used to group landmine responses with similar HMM model parameters, thus learning the number of distinct landmine responses within a data set. Model inference is accomplished using a fast variational mean field approximation that can be implemented for on-line learning.

7664-88, Session 14

Context-dependent feature selection using unsupervised contexts applied to GPR-based landmine detection

C. R. Ratto, P. A. Torrione, L. M. Collins, Duke Univ. (United States)

Context-dependent classification techniques applied to landmine detection with ground-penetrating radar (GPR) have demonstrated substantial performance improvements over conventional classification algorithms. Context-dependent algorithms compute a decision statistic by integrating over uncertainty in the unknown, but probabilistically inferable, context of the observation. When applied to GPR, contexts may be defined by differences in electromagnetic properties of the subsurface environment, which are due to discrepancies in soil composition, moisture levels, and texture. Context-dependent Feature Selection (CDFS) is a technique developed for selecting a unique subset of features for classifying landmines from clutter in different environmental contexts. In past work, context definitions were assumed to be soil moisture conditions known during training, and they were identified probabilistically using a feature-based technique. However, knowledge of environmental conditions could be difficult to obtain in the field. In this paper, we utilize an unsupervised learning algorithm for defining contexts with definitions that are unknown a priori. Our method performs unsupervised context identification based on similarities in

physics-based and statistical features that characterize the subsurface environment of the raw GPR data. Results indicate that utilizing this contextual information improves classification performance, and provides performance improvements over non-context-dependent approaches. Implications for on-line context identification will be suggested as a possible avenue for future work.

7664-89, Session 14

Landmine detection using ensemble discrete hidden Markov models with context dependent training methods

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We propose a landmine detection algorithm that uses ensemble discrete hidden Markov models with context dependent training schemes. We hypothesize that the data are generated by K models. These different models reflect the fact that mines and clutter objects have different characteristics depending on the mine type, soil and weather conditions, and burial depth. Model identification is based on clustering in the log-likelihood space. First, one HMM is fit to each of the N individual sequence. For each fitted model, we evaluate the log-likelihood of each sequence. This will result in an N x N log-likelihood distance matrix that will be partitioned into K groups. In the second step, we learn the parameters of one discrete HMM per group. We propose using and optimizing various training approaches for the different K groups depending on their size and homogeneity. In particular, we will investigate the maximum likelihood, Bayesian, and discriminative training approaches. Results on large and diverse Ground Penetrating Radar data collections show that the proposed method can identify meaningful and coherent HMM models that describe different properties of the data. Each HMM models a group of alarm signatures that share common attributes such as clutter, mine type, and burial depth. Our initial experiments have also indicated that the proposed mixture model outperform the baseline HMM that uses one model for the mine and one model for the background.

7664-90, Session 14

Comparison of different classification algorithms for landmine detection using GPR

A. Fadeev, A. S. Fadeev, H. Frigui, Univ. of Louisville (United States); P. D. Gader, Univ. of Florida (United States)

The Edge Histogram Detector (EHD) is a landmine detection algorithm that has been developed for ground penetrating radar (GPR) sensor data. It has been tested extensively and has demonstrated excellent performance. The EHD consists of two main components. The first one maps the raw data to a lower dimension using edge histogram based feature descriptors. The second component uses a possibilistic K-Nearest Neighbors (K-NN) classifier to assign a confidence value. In this paper we show that performance of the baseline EHD could be improved by replacing the K-NN classifier with model based classifiers. In particular, we investigate two such classifiers: Support Vector Machines (SVM), and Relevance Vector Machines (RVM). We investigate the adaptation of these classifiers to the landmine detection problem with GPR, and we compare their performance to the baseline EHD with a K-NN classifier. As in the baseline EHD, we treat the problem as a two class classification problem: mine vs. false alarm. Model parameters for the SVM and the RVM classifiers are estimated from training data using logarithmic grid search. For testing , soft labels are assigned to the test alarms. A confidence of zero indicates the maximum probability of being a false alarm. Similarly, a confidence of one represents the maximum probability of being a mine. Results on large and diverse GPR data collections show that the proposed modification to the classifier component can improve the overall performance of the EHD significantly.

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Fate study of water-borne gram positive vegetative bacterial cells with Raman microscopy

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We present a bacterial fate study of Gram positive vegetative cells in water via Raman spectroscopy monitoring. Two types of cells were considered for this study: vegetative cells of Bacillus cereus, Bacillus megaterium which contain the polyhydroxybutyric acid (PHBA) as an energy storage compound and Bacillus atrophaeus cells which do not. The cells were lyophilized after harvesting and at the onset of the study and suspended in de-ionized water at room temperature. Subsequent suspensions were deposited onto an aluminum slides at different times and allowed to dry. The cells were monitored periodically for over a week after the onset of starvation induced sporulation. Raman spectra from multiple regions of each dried spot and each deposit time were acquired along with the bright-field and fluorescence images. Resulting spectral data were examined to investigate the effect of suspension time on the spectral signatures as it relates to PHBA, polysaccharides and other spore coat formation chemicals as well as the fate behavior of the two types of cells investigated.

Development of an integrated system for rapid detection of biological agents

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Biological agents are as great a threat as nuclear or chemical weapons. They must be detected at the earliest stage upon dispersal to prevent the diffusion of these argents. Once these agents are dispersed into the air, however, it takes long time to detect them because several processes are needed to detect these agents. Furthermore, since recent advances in molecular biology make it easy make a wide variety of new biological agents, it is difficult to detect new agents.

Polymerase chain reaction (PCR) is a common method used to create copies of a specific target region of a DNA sequence and to produce large quantities of DNA molecules. A few DNA molecules are rapidly amplified by PCR into billions of copies. PCR is a key technology in genome-based biological analysis revolutionizing many in life science fields.

Therefore, we have developed an integrated system for rapid detection of biological agents captured from the air based on gene detection. Each of multiple modules was developed to increase the signal/noise ratio of the system.

Agents can be detected within 15 min from the capture. Moreover, operators are not exposed to samples collected from the air due to fully automated operation.

Estimation and discrimination of aerosols using multiple-wavelength LWIR lidar

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This paper presents an overview of recent work by the Edgewood Chemical Biological Center (ECBC) in algorithm development for parameter estimation and classification of localized atmospheric aerosols using data from rapidly tuned multiple-wavelength range-resolved LWIR lidar. The motivation for this work is the need to detect, locate, and discriminate biological threat aerosols in the atmosphere from interferent materials such as dust and smoke at safe standoff ranges using time-series data collected at a discrete set of CO_2 laser wavelengths. The goals of the processing are to provide real-time aerosol detection, localization, and discrimination. Earlier work by the authors has produced an efficient Kalman filter-based algorithm for estimating the range-dependent aerosol concentration and wavelength-dependent backscatter signatures. The latter estimates are used as feature vectors for training support vector machines classifiers for performing the discrimination. Several years of field testing under the Joint Biological Standoff Detection System program at Dugway Proving Ground, UT, Eglin Air Force Base, FL, and other locations have produced data and backscatter estimates from a broad range of biological and interferent aerosol materials for the classifier development. The results of this work are summarized in our presentation.

Application of the Raven UAV for autonomous real-time chemical and biological detection

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This paper presents flight test results from a series of outdoor chemical simulant tests conducted at Dugway Proving Ground in 2008 and 2009 employing a Raven UAV equipped with a real-time chemical sensor. The flights were conducted as part of a program under the sponsorship of the Army JPM NBC Contamination Avoidance and in conjunction with the Army PM-Unmanned Aircraft Systems, the Defense Threat Reduction Agency, and Edgewood Chemical Biological Center, and US ARMY Aviation & Missile Research, Development, & Engineering Center. These tests demonstrated the ability to autonomously detect and track a chemical plume, using the Chemical Sensor Module (CSM) in the Raven nose, during a variety of atmospheric conditions. During the testing, the Raven, with integrated CSM, conducted over a dozen flights, tracking outdoor releases of simulated chemical weapons over significant distances. The Raven was cued to the releases with standoff detection systems through Cursor on Target messages. Upon reaching the plume, the Raven used on-board sensors and on-board meteorological data to track the plume autonomously and determine the extent of the plume. Results were provided in real-time to the UAV operator.

The presentation and paper present the test results, including video of the telemetry, airborne videos, and quantitative results from the experiment. The paper also presents the plume tracking algorithms used to control the UAV during autonomous plume tracking operation.

7665-05, Session 1

Chamber lidar measurements of biological simulants

D. M. Brown, E. P. Thrush, M. E. Thomas, The Johns Hopkins Univ. (United States)

To ensure agent optical cross sections are well understood from the UV to the LWIR, volume integrated measurements of aerosolized agent material at a few key wavelengths is required to validate existing simulations. Ultimately these simulations will be used to assess the detection performance of various classes of lidar technology spanning the entire range of the optical spectrum. The present work demonstrates an optical measurement architecture based on lidar allowing the measurement of backscatter and depolarization ratio from biological aerosols released in a refereed, 1-m cubic chamber. During 2009, various upgrades have been made to the chamber LIDAR system, which operates at 1.064 µm with sub nanosecond pulses at a 120 Hz repetition rate. The first build of the system demonstrated a sensitivity of aerosolized Bacillus atrophaeus (BG) on the order of 5 x 10^5 ppl with 1 GHz InGaAs detectors. To increase the sensitivity and reduce noise, the InGaAs detectors were replaced with larger-area silicon avalanche photodiodes for the second build of the system. In addition, computer controlled step variable neutral density filters are now incorporated to facilitate calibrating the system for absolute back-scatter measurements. Calibrated hard target measurements will be combined with data from the ground truth instruments for cross-section determination of the material aerosolized in the chamber. Measured results will be compared to theoretical simulations of cross-sections and depolarization.

7665-06, Session 1

Optical properties and cross sections of biological aerosols

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There is an urgent need to develop standoff sensing of biological agents in aerosolized clouds. In support of the Joint Biological Standoff Detection System (JBSDS) program, lidar systems have been a dominant technology and have shown significant capability in field tests conducted in the Joint Ambient Breeze Tunnel (JABT) at Dugway Proving Ground (DPG). Unfortunately, the release of biological agents in the open air is forbidden. Therefore, indirect methods must be developed to determine agent cross-sections in order to validate lidar performance against biological agents. A method has been developed that begins with laboratory measurements of thin films and suspensions of biological material to obtain the complex index of refraction of the biological material from the UV to the LWIR. Using that result with particle size distribution and shape information as inputs to T-matrix or Mie calculations yields the extinction cross-section and backscatter cross-section as a function of wavelength. Depolarization ratio for any incident light polarization can also be attained from these calculations. Recent efforts to model field measurements from the UV to the IR have been successful. Measurements with aerodynamic and geometric particle sizers show evidence of particle agglomeration. Back-scatter simulations of these aerosols show these agglomerated particles dominate the aerosol back-scatter and depolarization signals. In addition, these large particles create spectral signatures in the back-scatter signal due to material absorption. Spectral signatures from the UV to the IR have been observed in simulations of field releases. This method has been demonstrated for a variety of biological simulant materials such as Ovalbumin (OV), Erwinia (EH) and Bacillus atrophaeus (BG). These spectral signatures may offer new methods for agent discrimination for both stand-off sensing and point detection systems.

7665-07, Session 2

Water matrix and age effects on bacterial spectra with Raman microspectroscopy

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Raman microspectroscopy is used to probe the growth parameters for bacterial detection in water backgrounds. Signature variability may occur from pathogens in water. No studies have been reported on the fate of Raman signatures over time for biologicals stored in water matrices. A FALCON II Raman Chemical Imaging System (ChemImage, Pittsburgh, PA) and 532 nm laser excitation source acquired the Raman spectra. MATLAB principal components (PC) analysis software was employed for data reduction. Suspensions of Bacillus globigii (BG), Bacillus thuringiensis (BT), and three strains of E. coli (EC) were prepared in distilled (DIW) and recipe tap water. Aliquots at 5 minutes, 5 hours, and 1, 2, and 7 days at 25C were dried on microscope slides in replicate. Adequate spectral differences were observed for all three organisms. PC analyses showed that the three EC strains coalesced, and all three bacterial species were separated. For BT and BG, a clear distinction between tap water and DIW was observed at all aging times. A good separation was observed for each EC strain in both water matrices, however, those six categories overlapped. Within each group, the time parameter poorly separated the suspensions as the aging proceeded. A Mahalanobis linkage distance analysis (dendrogram) for all three species in recipe tap water confirmed a random order for all five suspension times. Microscope analysis showed that freshly suspended spores remained as spores after seven days. Species and water matrix produced good spectral separations, while aging in DIW had no significant spectral effect.

7665-08, Session 2

Standoff lidar simulation for biological warfare agent detection, tracking, and classification

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Lidar has been identified as a promising sensor for remote detection of biological warfare agents (BWA). Elastic IR lidar can be used for cloud detection at long ranges and UV laser induced fluorescence can be used for discrimination of BWA against naturally occurring aerosols. This paper will describe a simulation tool which enables the simulation of lidar for detection, tracking and classification of aerosol clouds. The cloud model was available from another project and has been integrated into the model. It takes into account the type of aerosol, type of release (plume or puff), amounts of BWA, winds, height above ground and terrain roughness.

The model input includes laser and receiver parameters for both the IR and UV channels as well as the optical parameters of the background, cloud and atmosphere. The wind and cloud conditions and terrain roughness are specified for the cloud simulation. The search area including the angular sampling resolution together with the IR laser pulse repetition frequency define the search conditions. After cloud detection in the elastic mode, the cloud can be tracked using appropriate algorithms. In the tracking mode the classification using fluorescence spectral emission is simulated and tested using correlation against known spectra. The simulation estimates and displays the particle concentration as well as the goodness of fit for the classification using fluorescence.

Examples of simulations will be given and discussed in relation to experimental data. Further improvement of the model to include terrain reflection, full 3D scanning and other features will also be discussed.

7665-09, Session 2

Short-range lidar for bio-agent detection and classification

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(Canada); J. Simard, S. Buteau, J. E. McFee, Defense Research
and Development Canada (Canada)

We have developed a small, relatively lightweight and efficient short
range (<100 m) LiDAR instrument for remotely detecting harmful
bioagents. The system is based on a pulsed, eye-safe, tripled (355nm)
diode pumped Nd:YAG laser, exciting components which then fluoresce
with a typical spectrum. The system makes use of a novel technology
for 24 h / 7 days-a-week monitoring for the presence of unusual
concentrations of fluorescing bioaerosols at a precise remote location
within the monitored area, with response within seconds. Fluorescence
is detected through a telescope / fiber bundle / spectrograph / multi-
channel detector system capable of photon counting. Spectra are
measured in the 425 to 700nm visible range. Preliminary results show a
sensitivity level of ~200 ACPLA of Bacillus Globigii, an anthrax simulant,
at a distance of 100 m (assume worst case where 1 ppl = 1 ACPLA)
considering particles between 0.5 and 10 micron, with a geometric
mean at 1 um, during dry releases. The apparatus has been tested in the
field during two test and evaluation campaigns with multiple bioagents
(Bacillus Globigii, Cereus, Neurospora, Penicillium, etc.) and public
security products (mace, pepper spray, blast grenades, etc.) Preliminary
results show that the system is able to distinguish harmful bioagents
from naturally occurring ones. A classification algorithm was successfully
tested with a single type of bioagent; experiments for mixtures of
aerosols and daytime measurements are discussed.

7665-10, Session 2

Biological aerosol standoff detection leveraging particle asymmetry and size

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Tracy, J. R. Colosimo, S. M. Ashby, R. G. Nichols, N. R. Woody,
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Standoff detection and discrimination of biological aerosols provides
a critical advantage for the protection of the war fighter. Standoff
detection of biological aerosols is based on the measured aerosol
optical properties in conjunction with situational awareness. Since 2004
Lockheed Martin Coherent Technologies has measured aerosol optical
properties of biological aerosol and interferents as part of the Defense
Threat Reduction Agency (DTRA) and Joint Biological Standoff Detection
System (JBSDS) programs to develop robust standoff detection
capabilities. Measurement of the elastic backscatter and the partitioning
of backscattered intensity between polarization states provide robust
measurement capability for detection of aerosols over standoff distances
beyond 4 km. Selection of appropriate wavelength combinations for
the measurement of polarization and elastic backscatter probes the
particle shape, size, and absorptive properties allowing discrimination
of bioaerosol threats from interferents. Real-world challenges such
as cost, complexity and optical attenuation of the atmosphere limit
wavelength options. The WANDER technology (Wavelength Normalized
Depolarization Ratio) has been developed around key wavelengths
and utilizes measurements to probe the aerosol optical properties with
limited atmospheric effects and maximum discrimination potential.
This presentation focuses on measured and modeled aerosol
optical properties of bioaerosol simulants and interferents based on
governmental testing in desert environments (Dugway Proving Ground)
and humid environments (Eglin Air Force Base). Details associated with
variability of the optical signatures, the environmental sensitivity of the
optical signatures (e.g. relative humidity), and potential measurement
artifacts will be discussed.

7665-11, Session 3

Information fusion of standoff and other information for biodefense decision support

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Information fusion aims at synergistic exploitation of multiple information
sources. This paper discusses selected aspects of an MIT Lincoln
Laboratory effort developing information fusion techniques for biodefense
decision-support tasks, involving biological standoff (LIDAR - Light
Detection and Ranging) sensors, meteorology, as well as point sensors
and potentially other battlespace sensing and contextual information.

An approach developed for bioattack detection, referred to as
Spatiotemporal Coherence (STC) fusion, combines phenomenology
aspects with uncertainty measures to quantify corroboration between
various available information elements. STC extends beyond heuristics
since it is based on physical model aspects. Approximate uncertainty
quantification provisions make it more than model-based, affording it
some advantages seen in fuzzy approaches. Furthermore, STC has
adaptive extensions. The results of computational experiments indicate
that STC fusion can significantly reduce false-alarm rates. The results
also suggest that information fusion can lessen detection-task sensitivity
to sensor positioning.

Techniques developed for the individual plume progression ground-
truth data needed for this research include Release Augmentation,
and Meandering Plume and Background Simulation. The first allows
generation of release-in-background cases from simulant-release
measurements at test sites and background measurements at other
locations. The second allows computationally-efficient simulation of
numerous individual release-in-background sequences for a variety of
release parameters and background conditions, and includes turbulence
and meandering effects.

The effort extends beyond the detection realm to higher-level
information-fusion tasks. In particular, a multisource information fusion
based plume-mapping approach was developed. Thus, the developed
techniques address a range of problems from detection-task false-alarm
rate reduction to higher-level tasks of threat mapping and propagation
prediction.

7665-12, Session 3

Modeling of spectral emission-based lidar remote sensing

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Stand-off Laser-Induced-Thermal-Emission (LITE), Laser-Induced-
Breakdown Spectroscopy, (LIBS) and remote Raman Lidar are being
studied for the remote sensing of a wide range of target substances,
including explosive and chemical species. Each of these techniques use
a transmitted laser beam to remotely excite a spectral emission process
at a distant target, have some optical and detection characteristics in
common, but also have several other excitation and delivery aspects
that are unique to each technique. In order to better understand these
techniques, we have developed a program to model and simulate a LITE,
LIBS, and Raman lidar system for the stand-off detection and spectral
identification of close to moderate range target species. In particular, a
modified lidar equation has been developed for each technique, in which
the influence of the transmission of the atmosphere is also computed
to determine its influence on the backscattered spectral information as
a function of wavelength and range. The standard Lidar equation was
modified to take into account the emission of a laser induced source at
a range r, and the subsequent transmission of the emission back toward

the (Lidar) telescope receiver. The emission term is different for LITE, LIBS, and Raman Lidar cases.

7665-14, Session 3

A rapidly deployable chemical sensing network for the real-time monitoring of toxic airborne contaminant releases in urban environments

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The ability to analyse the chemical composition or quality of air samples in a controlled environment is easily demonstrated, but the problem becomes extremely complex when translated to an unconstrained outdoor environment. Here the sensors are faced with the need to identify very low particle counts, often in the presence of high levels of benign pollutants and rapidly changing turbulent meteorological conditions.

The DYCE project has been set up to address the needs of military and blue light responders in providing a rapid, reliable on-scene analysis of the dispersion of toxic airborne contaminants following their malicious or accidental release in an urban or industrial environment.

The system comprises a small network of portable ad-hoc deployable sensor nodes that are able to monitor and react to changing local conditions and chemical data to enable end-users to dynamically optimise their locations. Each node is built around the SELEX GALILEO Hydra platform fitted with solid state meteorological sensors and a Nexsense-C Field Asymmetric Ion Mobility Spectrometry (FAIMS) based chemical detector. The FAIMS detector provides a capability to rapidly detect and identify chemical warfare agents and toxic industrial chemicals.

This paper presents an overview of the project and results on methods to:

- Identify and locate the source of the contaminant release.

- Monitor and estimate the dispersion characteristics of the plume.

- Monitoring localised changing environmental conditions and understanding their repercussions on the mission.

- Deployment planning to optimise the data gathering mission given a constrained asset base.

7665-15, Session 3

A framework for evaluating mixture analysis algorithms

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In recent years, several sensing devices capable of identifying unknown chemical and biological substances have been commercialized. The success of these devices in analyzing real world samples is dependent on the ability of the on-board identification algorithm to de-convolve spectra of substances that are mixtures. To develop effective de-convolution algorithms, it is critical to characterize the relationship between the spectral features of a substance and its probability of detection within a mixture, as these features may be similar to or overlap with other substances in the mixture and in the library. While it has been recognized that these aspects pose challenges to mixture analysis, a systematic effort to quantify spectral characteristics and their impact, is generally lacking. In this paper, we propose metrics that can be used to quantify these spectral features. Some of these metrics, such as a modification of variance inflation factor, are derived from classical statistical measures used in regression diagnostics. We demonstrate that these metrics can be correlated to the accuracy of the substance's identification in a mixture. We also develop a framework for characterizing mixture analysis algorithms, using these metrics.

Experimental results are then provided to show the application of this framework to the evaluation of various algorithms, including one that has been developed for a commercial device. The illustration is based on synthetic mixtures that are created from pure component Raman spectra measured on a portable device.

7665-16, Session 3

Cooperative autonomous mobile point sensors

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CBRN point sensors typically have more sensitivity and capability than standoff sensors, therefore it may be desirable to deploy point sensors in a protective configuration around high value assets. Deploying point sensors in such a configuration at a distance sufficient for early warning protection is often prohibitive due to the inherent logistics, risks, and unmanageable number of required sensor assets. This paper describes an approach for using fewer, autonomously controlled, mobile point sensors to provide adaptive perimeter protection influenced by changing winds, threats, and command objectives. The proposed approach may be applied to stationary point sensing or cued, mobile threat interrogation for the purpose of providing advanced threat warnings for both static and mobile assets. The described concept consists of multiple autonomous VTOL (vertical take-off and landing) platforms acting cooperatively in response to operator commands, identified and possible threats, changing environmental conditions, and varied terrain. Command and control algorithms have been developed and demonstrated in simulation to elicit robust and complex behaviors with the goal of autonomously deploying and repositioning point sensors while maintaining a communications link with assets under protection. The algorithms used to efficiently and cooperatively arrange point sensors to accommodate threat locations, wind direction, and line of sight (for maintaining consistent communications throughout the sensor network), are described in detail. Ongoing efforts to migrate these algorithms to hardware demonstration platforms are also described.

7665-17, Session 3

Sensor-netting algorithm for chem/bio threat mapping from MESH, Inc.

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Many of the sensors used by the military present qualitative information to the user (e.g. alarm or no alarm) as opposed to quantitative measurements made by scientific instrumentation. The SNA is able to use the qualitative inputs by assigning them very large error bars. Because the SNA has a broader picture of the situation (it has information from many sensors spread out over the theater of operation), it can evaluate the input from each of the sensors and dynamically assigned noise and error characteristics to that sensor. In this way, the SNA will learn about each sensor and improve its mapping ability as time goes on by changing the weighting factors dynamically.

SNA is a hierarchical algorithm. A SNA running at the lowest level would be receiving inputs only from a group of sensors and map only the area covered by that group. SNA at a higher level would received inputs from SNAs and sensors and provide situational awareness over a wide area.

7665-58, Poster Session

Fluorescence-based optical chemical sensors for personal protection

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The World Health Organization has reported that each year approximately 3 million people are poised by organophosphates substances (pesticides and nerve agents) resulting in 220,000 deaths. Organophosphates are toxic compounds which causes inhibition of acetylcholinesterase, which is vital to nerve function. This inhibition is often fatal. A release of a nerve agent has the potential to rapidly affect a large number of people. The ease of manufacturing and dispensability nerve agents, as well as available, inexpensive starting materials make these agents a weapon of choice for criminal terrorist attacks. One of the major steps toward protection against dangerous substances is to develop sensor devices that can act as an early warning system to the endangered people.

The development of an early warning system, based on detection of toxic materials, is an important topic for research and development. Fiber optic sensor systems provide with numerous advantages over conventional systems which include immunity to electromagnetic interference, small and compact size, sensitivity, ability to be multiplexed, remote sensing and to be embedded into textile structure.

Here, we present an optical sensor for the detection of organophosphates nerve agents stimulant by incorporating of indicator dye in sol-gel thin films. The detection method is based on fluorescence quenching of the indicator dye. For the preparation of sol-gel thin films effect of using different organically modified sol-gel precursors have been studied. All thin-films were evaluated with respect to sensitivity, selectivity, response time, detection limit, dynamic range and regeneration. Sol-gel thin-films with a high content of organically modified sol-gel precursors yielded stable layers with fast response, good sensitivity and good reproducibility in signal change.

7665-59, Poster Session

Cold plasma decontamination using flexible jet arrays

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Cold plasmas can be formed by simply passing an inert gas, such as helium, over a sharp conductive point that is held at high voltage and high frequency, producing a luminous atmospheric discharge jet. Independently tunable parameters of electrical energy input, and gas flow rate, can be selected to produce a plasma jet that is very mild on surfaces, yet very effective in sterilizing that surface. Modes of action include plasma electron and ion bombardment, UV illumination from the discharge, free radical and some ozone production, and transient electro-static accumulation which can burst the membranes of microorganisms. These effects can also break chemical bonds, which find use in the decontamination of simulated chemical warfare agents, without producing toxic byproducts. Similarly, plasmas are effective at surface cleaning, and provide for their use in radiological "dirty bomb" cleanup by assisting in the removal of radionuclide contamination. For decontamination of a given area to proceed quickly, a sufficiently large array of plasma jets is employed, and operated so that dwell times are short. Planar arrays of 36 sq. in. consisting of 45 plasma jets have previously been demonstrated, but their effectiveness is limited to essentially flat surfaces. In order to adapt to contoured or irregular surfaces, the jet arrays are now mounted on a flexible surface. For very large jet arrays, perhaps of square meter areas, consumption of the inert helium gas can become a limiting factor. Issues of helium recycling and plasma operation with varying degrees of air contamination are considered.

7665-60, Poster Session

Sensor-and-dynamic model-enabled deliberate/accidental chemical/biological contamination assessment system dedicated to situational awareness of critical water distribution infrastructure security and water quality

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Drinking water systems are vulnerable to deliberate [terrorist attacks/sabotage] and accidental contamination with classical and/or non-traditional chemical agents, toxic industrial chemicals and/or toxic industrial materials as well as bilogical agents. An approach that utilizes off-the-shelf broad-spectrum analytical instruments coupled with advanced interpretive algorithms to provide detection-response networks for water is described. The system is shown to be a practical measure to detect and characterize (via unique chemical signatures ("fingerprint") response data] water distribution network backflow events involving toxic chemicals. This instrumentation has been certified by the Office of Homeland Security for detecting deliberate and/or accidental contamination of critical water infrastructure. This report summarizes the implications for deploying distribution based detection-protection systems. Several detection proprietary analytical systems have been installed at selected Army installations as well as the private sector. Real world deployment data is used to demonstrate recognition and classification of actual events and heuristic capabilities of the system along with its potential role in enhancing water quality above and beyond its obvious security aspects. For instance, the thousands of miles of existing water distribution network physical infrastructure in the United States [piping] may experience corrosion related water quality problems.

The work which will be presented involves the integration of several mature technologies [sensors, SCADA, dynamic models] into a complete security/corrosion detection and management system designed to protect the public and water related infrastructure. The combination of these systems provide decision makers with a "living model" that provides near real-time system-wide situational awareness of system safety, performance and infrastructure status.

7665-62, Poster Session

Standoff detection of explosives by differential reflectometry

T. A. Dubroca, R. E. Hummel, Univ. of Florida (United States)

Devices capable of detecting explosive materials should be fast, portable, inexpensive, reliable, harmless, and protect the privacy of humans. We are presenting the development of hardware in combination with software to detect traces of explosives using differential reflectometry (DR) which possess all of the above-mentioned attributes. Moreover, differential reflectometry does not require contact with the explosive substance, that is, it is a standoff technique.

Briefly, the DR shines ultra-violet and blue light on a surface. Upon reflection, the light is collected with a spectrometer combined with a CCD camera. A computer digests the resulting data and produces in turn a differential reflection spectrum taken between two adjacent areas of the surface. This differential technique is highly sensitive and provides spectroscopic data of materials, specifically of explosives. As an example, TNT displays strong and distinct features near 420 nm, and 250 nm. Similar, but distinctly different features are observed for other explosives. In addition, we present the development of algorithms which classify the resulting signals into explosives or non-explosives categories.

In short, the DR produces spectroscopic "fingerprints" of explosive

materials and distinguish them from harmless substances. Upon classification, a visual or acoustic signal would let the security personnel know in real time if traces of explosives have been detected.

7665-63, Poster Session

Standoff identification of UXO's and chemicals using Raman spectroscopy

R. Cox, B. Ray, B. Williams, M. Russell, K. Carron, DeltaNu (United States)

We will demonstrate results from a portable stand-off Raman system for identification of high energy material with stand-off capabilities from 0.3 m to 3.0 m. Video imaging is used to position the detection laser on the target, and the autofocus feature is used to collect high quality Raman spectra for matching unknown materials. Data is presented describing the angle of incidence of collection and the amount of material that can be identified at different ranges. Standoff systems are capable of identifying hazardous materials including CW agents (chemical warfare), UXO's (unexploded ordinances), TICS (toxic industrial chemicals) and TIMS (toxic industrial materials).

7665-18, Session 4

Standoff hyperspectral imaging of explosives residues using broadly tunable external cavity quantum cascade laser illumination

B. E. Bernacki, M. C. Phillips, Pacific Northwest National Lab. (United States)

We describe experimental results on the detection of explosives residues with active hyperspectral imaging by illumination of a target surface using an external cavity quantum cascade laser (ECQCL) and imaging using a room temperature microbolometer camera. Explosives have rich absorption features in the molecular fingerprint region that spans 500 to 1500 cm-1 which is easily probed by the wavelength range of quantum cascade lasers (QCLs). We used a custom-built ECQCL operating in a quasi-CW mode with a 100 kHz modulation rate and swept across a tuning range from 983.8-1102.95 cm-1 (9.07-10.16 µm) in 2 seconds. The active hyperspectral imaging technique forms a hypercube by recording images synchronized with the wavelength tuning of the ECQCL. For these experiments, 60 images were acquired at a camera frame rate of 30 Hz, giving a spectral resolution of 2 cm-1, which is sufficient for resolving the broad spectral features of solid explosive residues. The spectral information at each pixel of the resulting hyperspectral image can be used to identify the explosive type and relative quantity using the extensive library of spectral identification approaches developed initially in the remote sensing community. These techniques include spectral feature fitting, matched filtering, and spectral angle mapping. Mixtures of materials can be evaluated using linear spectral unmixing approaches and matched filtering or mixture tuned matched filtering. We provide examples of these identification methods using ENVI, a commercial spectral image processing software package.

7665-19, Session 4

Stoichiometric analysis of ammonium nitrate and ammonium perchlorate with nanosecond laser-induced breakdown spectroscopy

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Laser Induced Breakdown Spectroscopy is a potential technique for qualitative and quantitative measurements capable of handling samples in all forms [1]. Standoff detection of explosive residues has been demonstrated for distances up to 45 m and discrimination for distances up to 20 m [2]. The LIBS data, in general, uses delayed and gated collection of the signal. However, in this study we used an Ocean Optics 4000 spectrometer without delay and gating to obtain the LIBS spectra. The samples ammonium nitrate (AN) and ammonium Perchlorate (AP) used in this study were in pellet form (mixed with KBr) and were irradiated by 532 nm Nd:YAG laser pulses. The LIBS spectra exhibited characteristic lines corresponding to O, N, H, C, and K. The Oxygen line at 777 nm and Nitrogen line at 742 were used for evaluation of Oxygen/Nitrogen ratios. The intensities were calculated using area below the peaks and normalized to their respective transition probabilities and statistical weights. The O/N ratio estimated from the LIBS spectra was 3.68 for AP and 1.9 for AN. The intensity ratios show good agreement with the actual stoichiometric ratios - four for AP and one for AN.

7665-20, Session 4

Standoff trace-detection of explosives by imaging IR-backscattering laser spectroscopy

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All Explosives exhibit strong characteristic absorbance patterns in the mid-infrared (MIR) spectral range. These characteristic absorbance patterns open the possibility for optically based stand-off detection. Most recently quantum cascade (QC) lasers have been established as robust and versatile light sources offering high luminosity in the infrared spectral range. A broadly tunable infrared laser source can be realized by using a QC laser as an active element in an external cavity (EC) system.

We present experimental results on a QC laser embedded in an external cavity. Broad band tuning exceeding 100 cm-1 covering the characteristic absorbance of TNT around 7.5 µm wavelength is demonstrated. We realized a stand-off detection set-up by combining the tunable EC QC laser with a high performance IR imager. With active illumination of the scene, by tuning the laser a hyperspectral data cube is produced. The system avoids cross-sensitivity by performing multivariate analysis of the hyperspectral data. A diamond-based double-diffuser serves for reduction of laser speckles. The set-up is able to detect low surface contaminations of TNT (< 10µg/cm^2) on real world objects within one second. Limitations and perspectives of the MIR backscattering technique are discussed.

7665-21, Session 4

Free surface microfluidic/SERS for detection of gas-phase DNT

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A novel microfluidic/SERS platform has been developed for real time sensing of airborne explosives. The fundamental research is being conducted at UCSB, commercialized by SpectraFluidics, and validated at ECBC. The system leverages phenomena at multiple length scales, ranging from tens of micrometers to several nanometers. The key enabling technology is a newly developed invention termed Free-Surface Fluidics (FSF), where one or more fluidic surfaces are confined by surface tension forces, and exposed to the surrounding atmosphere. The free-surface fluidic architecture is combined with surface-enhanced Raman spectroscopy (SERS) for direct detection of airborne explosives. Once analyte molecules are absorbed into the flow, they can interact with gold or silver colloidal particles. This architecture allows for analysis and deterministic control of SERS 'hot spot' aggregation, which can increase

Raman scattering signal strength by up to 10 orders in magnitude.

The sensor is in advanced state of development which includes both strategies for wafer-level production of the sensor chip itself as well as the development of a chip holder that provides the required heating, cooling and humidity sensing that enables the microfluidic device to operate continuously under varying environmental conditions of temperature and relative humidity. The device has been shown to detect successfully the vapor emanating from a broad range of solid and liquid high-energy molecules in ambient air. For example, we have successfully measured DNT vapor at concentrations as low as ~1 ppb. This sensitivity value is confirmed by orthogonal measurements using GC-mass spectroscopy at ECBC.

7665-22, Session 4

Backpack explosives detection system for rapid trace-residue analysis

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Explosive ordinance disposal (EOD) and first responder units need a tool that allows them to make rapid assessments of the presence of explosives on or near an object of interest. Current tools for detecting explosive residues are limited in their scope of operation and may require a long analysis times (~30s). In an attempt to improve this situation, Alakai Defense Systems is developing a man-portable Backpack Explosives Detection System (BEDS) that uses double-pulse Laser Induced Breakdown Spectroscopy (DP-LIBS). The system uses two small hand-held lasers with a fiber coupled sampling head to create a plasma on a target placed a few millimeters from it. Atomic emission from the small plasma on the target is then collected by special optics inside the gun-like head and sent to a backpack computer for spectral processing. The user is then notified of the presence of explosive residue within 1 second. Results of a variety of explosives on a variety of substrates will be presented. The future use and ultimate design goals for the system are also presented.

7665-23, Session 4

Trace detection of explosive compounds by different laser-based techniques at the ENEA Laboratories

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Recently the ENEA Laser Application Section has participated to the European project ISOTREX (Integrated system for on-line trace explosives detection in solid and vapour state), funded in the frame of the PASR 2006 with the main aim to exploit different laser based techniques. In our laboratory we have tested LIBS, LPAS and SERS technologies on standard explosive compounds. Results of the measurements with detection limits of samples monitored, for each techniques, are presented in view of their possible integration in a single device for trace detection, might contribute also to drastically limit the number of false positives.

7665-24, Session 5

Nd:YAG-CO$_2$ double-pulse laser-induced breakdown spectroscopy for explosive residues detection

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Univ. of Central Florida (United States); M. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Laser induced breakdown spectroscopy (LIBS) has showed advatages for remote detection thanks to its ability to analyze virtually any target material, with little to no sample preparation and both optical delivery and detection. Remote LIBS is therefore an attractive analytical technique for detection of potentially hazardous materials/environments. When compared to other analytical techniques such as inductively coupled plasma mass spectrometry (ICP-MS), LIBS suffers from poor sensitivity and hence limit of detection. The double-pulse LIBS approach has been used as a method of enhancing the signal-to-noise ratio in both conventional and remote LIBS. To further develop double-pulsed LIBS, this study focused on the properties of laser induced plasmas using multi-wavelength (1.064 µm / 10.6 µm) excitation dual pulsed LIBS. The system utilized in this study consisted of a Q-switched Nd:YAG laser at fundamental wavelength and transverse excited atmospheric (TEA) CO2 laser in a collinear dual pulse configuration. In order to apply this technique to thin film and residues samples, we proceed in a systematic study of the properties of the plasma on a spin-coated thin polystyrene film. Signal and signal-to-noise (S/N) enhancements are compared for atomic carbon and molecular CN and C2 emission lines. The applicability of this technique to the detection and discrimination of organic sample in non-controlled atmospheric conditions is examined. Application to the LIBS signature of 2,4,6-TNT residues is discussed based on enhancement properties and molecular signature to address the analytical potential of this technique for explosive residues detection.

7665-25, Session 5

Laser vaporization of trace explosives for enhanced noncontact detection

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Trace explosives contamination comes mainly in the form of solid particulates on surfaces, due to the low vapor pressure of most explosives materials. Today, the standard sampling procedure involves physical removal of particulate matter from surfaces of interest. A variety of methods have been used including air jetting or swabbing surfaces of interest. Ultimately, the sampled particles are heated to generate vapor for analysis in hand held, bench top, or portal detection systems. These sampling methods are time-consuming and costly but also non-selective, allowing non-explosive particles to be co-sampled and analyzed with the explosives. This can adversely affect the sensitivity and selectivity of detectors, especially those with a limited dynamic range. We present a novel sampling technique that is targeted, non-contact, and which selectively removes trace explosive signatures, thus improving the selectivity and sensitivity of existing detectors. The method involves the illumination of a surface of interest with infrared laser light with a wavelength that matches a distinctive vibrational mode of an explosive. The resonant coupling of laser energy results in rapid heating of explosive particles and rapid release of a vapor plume. Neighboring non-explosive particles are not directly heated as their vibrational modes are not resonant with the laser. The generated vapor plume has a higher concentration of explosives than if the particles were heated with a non-selective light source (e.g. heat lamp). We present results with both benchtop infrared lasers as well as miniature quantum cascade lasers. This research is sponsored by the DHS Science and Technology Directorate

7665-26, Session 5

Intricacies of comparative testing of explosives detectors at the ultra-trace level

R. J. Harper, M. E. Fisher, ICx Nomadics, Inc. (United States)

This paper shall demonstrate the reduced lifetime of ultra-trace

explosive residues when subjected to standard laboratory conditions, citing examples of flawed experimental design and providing learning outcomes. The traditional view of "trace" level residue may lie within the detection limit capabilities of bench-top instrumentation, and whereas gas chromatography / mass spectrometry, often the main stay of many trace evidence analysis laboratories can readily deliver nanogram and now potentially upper picogram detection limits, emerging technologies continue to push the limits of detection, and sub-nanogram restrictions give way to picogram and femtogram opportunities.

As instrument technologies get more sensitive, the need to work at continually lower detection levels is expressed, and the generation of reliable, reproducible ultra-trace samples for the testing, analysis and evaluation of those technologies is challenged by the chemical properties of the very samples under investigation. Unlike testing of bulk quantities explosives, unforeseen sublimation and sorption phenomena may occur at the picogram level, potentially disrupting an otherwise well planned test. Many explosives would generally be expected to be stable at room temperature for a period of time, and so to the inexperienced operator, failure to take account of the ultra-trace properties may result in the misrepresentation of a sensor's capabilities.

The analyst is now faced with the complication of working with amounts of explosive so potentially low, that loss of a few picograms of material due to evaporation, air currents, poor laboratory technique or some other diluting factor, represents a significant percentage of the total sample mass, and added to the complication are sample and substrate matrix, carry-over, and potential cross contamination effects that may now pose a significant effect rather than a slight background nuisance.

7665-27, Session 5

Electro-optical signatures of homemade explosive detonations

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Recently, electro-optical measurements were made to aid the characterization of electro-optical emissions from homemade explosive detonation fireballs. Eleven explosives, weighing between 20 to 100 lbs. and mostly comprised of nitrate salts, were manufactured and detonated. Visible and infrared fireball signatures were collected using two Fourier transform spectrometers, two thermal imaging cameras, a radiometer, and a 3 CCD digital video camera. The spectrometers collected interferograms at 82 Hz at a spectral resolution of 16/cm. The four-channel radiometer acquired band-integrated intensities at 100 kHz. Thermal imagers each had a maximum 640x512 pixel resolution with a 25 µm pixel pitch with variable frame rates depending on window size. Infrared spectra indicated a sooty fireball dominated by continuum radiation. Radiant fireball emissions decayed rapidly with a ten-fold decrease in peak integrated intensity occurring within 300 ms. Upon detonation, the homemade explosives produced a soil-dust cloud which surrounded the post-detonation combustion fireball and strongly attenuated the radiant emissions. Visible signatures revealed gray soot within the dust cloud. The duration of radiant fireball emissions and explosive weight were correlated with larger explosive fireballs persisted longer than smaller ones. Temporal analysis of the radiometer signatures collected at 100 kHz may hold the key to battlefield classification of these fast transient events. An overview of the detonation signatures will be presented and phenomenological insight will be discussed.

7665-28, Session 6

Laser-induced breakdown spectroscopy of RDX and HMX with nanosecond, picosecond, and femtosecond pulses

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Laser-induced breakdown spectroscopy (LIBS) has a number of

properties that makes it attractive for the detection of explosives, including stand-off detection capability, constraint of a very small amount of material, and high detection speed [1,2]. Ultrashort laser pulses with duration in the picosecond (ps) or femtosecond (fs) range represent attractive laser sources to design novel and sensitive LIBS systems [3]. The use of short pulses is gaining attention predominantly because it provides certain benefits related to both fundamental studies and delicate analytical problems (e.g. formation of filaments for remote detection). Herein we present some of our results on the LIBS measurements of RDX and HMX using ns, ps, and fs pulses. RDX and HMX were mixed with KBr and pellets were prepared for spectroscopic studies. Ns pulses at 532 nm, ps/fs pulses at 800 nm were used for the experiments. The spectra were collected using Ocean Optics 4000 spectrometer. Several features were observed in the spectra, collected without gating and delay, exclusive for each pulse domain. The differences/similarities in the spectra collected using different pulses and details of their origin will be presented in detail.

7665-29, Session 6

Compact standoff Raman system for detection of homemade explosives

A. K. Misra, S. K. Sharma, D. E. Bates, T. E. Acosta, Univ. of Hawai'i (United States)

We will present data on standoff detection of chemicals used in the synthesis of homemade explosives (HME) using a compact portable standoff Raman system developed at the University of Hawaii. Data will be presented to show that good quality Raman spectra of various hazardous chemicals such as ammonium nitrate, potassium nitrate, potassium perchlorate, sulfur, nitrobenzene, benzene, acetone, gasoline, various organic and inorganic chemicals etc. could be easily obtained from remote distances with a compact standoff Raman system utilizing only a regular 85 mm Nikon camera lens as collection optics. Raman spectra of various chemicals showing clear Raman fingerprints obtained from targets placed at 50 m distance in daylight with 1 to 10 second of integration time will be presented. A frequency-doubled mini Nd:YAG pulsed laser source (532 nm, 35 mJ/pulse, 20 Hz, pulse width 8 ns) is used in an oblique geometry to excite the target located at 50 m distance. The standoff Raman system uses a compact spectrograph of size 10 cm (length) x 8.2 cm (width) x 5.2 cm (high) with spectral coverage from +100 cm-1 to -4445 cm-1 (Stokes-Raman shifted from 532 nm laser excitation) and is equipped with a gated thermo-electrically cooled ICCD detector. The system is capable of detecting both the target and the atmospheric gases before the target. Various chemicals could easily be identified through glass, plastic and water media. Possible applications of the stand-off Raman system for Homeland security and environmental monitoring will be discussed.

7665-30, Session 6

Detection of explosives at trace levels by laser-induced breakdown spectroscopy (LIBS)

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With the aim of realizing a compact instrument for detection of energetic materials at trace levels, laser induced breakdown spectroscopy was applied on residues from nine explosives in air surroundings.

Different potentially interfering organic materials were also analyzed. The residues were not uniformly distributed on an aluminum support and single-shot discrimination was attempted. For a single residue type, large shot-to-shot fluctuations of the line intensity ratios characteristic for organic samples were observed, which made material classification difficult. It was found that both atomic and molecular emission intensities, as well as their ratios, are strongly affected by an amount of the ablated

support material, which mainly determines the plasma temperature. With respect to the spectra from the clean support, emission intensities of atomic oxygen and nitrogen are always reduced in the presence of an organic material, even if its molecules contain these elements. This was attributed to chemical reactions in a plasma containing carbon or its fragments. Hydrogen atomic emission depends strongly on the local humidity above the sampled point and its line intensity shows shot to shot variations up to 50%, also on a homogeneous sample.

It is argued that shock waves generated by previous spatially and/or temporally close laser pulses blow away a relatively heavy water aerosol, which later diffuses slowly back towards the sampled point. C2 and CN exhibit a peak emission behavior with atomic Al emission, and their variable ratio indicates an existence of different formation or removal mechanisms from the plasma, depending on the plasma parameters and on the composition of the organic residue. On the basis of these observations, an attempt is made to establish a suitable procedure for data analysis and to determine the optimal experimental conditions, which would allow for discrimination of explosives from other, potentially interfering, residues. Correct classification was always obtained for five types of explosives, while for TATP, nitroglycerine and EGDN this occurred only for thin residues.

7665-31, Session 6

Xerogel-based molecularly imprinted polymers for explosives detection

E. L. Holthoff, D. N. Stratis-Cullum, U.S. Army Research Lab. (United States)

Molecularly imprinted polymers (MIPs) can be utilized as artificial recognition elements for target chemical analytes of interest. Molecular imprinting involves arranging polymerizable functional monomers around a template followed by polymerization and template removal. The selectivity for the target analyte is based on the spatial orientation of the binding site and covalent or noncovalent interactions between the functional monomer and the analyte. The polymer materials of particular interest are sol-gel-derived xerogels. To allow for increased target recognition, the xerogel has specific functional groups, which allow for polymer interactions with the template molecule (and target analyte). The objective of the present work is to create a sensitive and selective MIP for 2,4,6-trinitrotoluene (TNT). A quartz crystal microbalance and surface enhanced Raman scattering (SERS) are used to investigate the capability of these MIP materials in a sensor platform.

7665-32, Session 7

Self-channeled laser-induced breakdown spectroscopy for detection of organic compounds in atmosphere via their molecular signature

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It has been shown that Laser-Induced Breakdown Spectroscopy (LIBS) has unique capabilities for detection and identification of explosive and chemical threats. To handle practical hazard protection scenarios, stand-off detection distances exceeding 100 meters are ideally needed. Femtosecond Laser Self-Channeling can provide a high energy-density source of light at the kilometer range by creating a self-guided filaments of light, with high intensity (50 TW/cm²). Self-channeled Laser Induced Breakdown Spectroscopy (SC-LIBS) reveals to be a one-of-a-kind technique.

In order to improve the remote detection of energetic materials, primary studies at close ranges of detection are needed. In the present study, carbon-based samples (graphite, polymer and explosive-like thin films) are irradiated by self-channeled light filaments produced by a 20 mJ, 45 fs, 800 nm laser. The spectral signatures from samples of energetic materials are characterized, with an emphasis on transitions in atomic and ionized C, H, O, and N, as well as and molecular (C2 and CN) transitions. Initial results show the predominance of molecular signatures rather than atomic emission in this technique. This study focuses on understanding the mechanisms of origin of the molecular signature during plasma expansion in different atmospheric conditions from an organic material in order to apply them for an analytical purpose. A comparative analysis between hydrodynamic and chemical kinetic plasma modeling and the experimental results is conducted. From the application point of view, the analytical performance for the detection and discrimination of organic samples via this LIBS configuration will be discussed.

7665-33, Session 7

Extension of a standoff explosive detection system to CBRN threats

A. R. Ford, R. D. Waterbury, J. D. Rose, K. R. Pohl, E. L. Dottery, Alaka'i Consulting & Engineering, Inc. (United States)

Recent progress is reported on a multi-threat chemical, biological, radiological, nuclear, and explosive (CBRNE) laser standoff detection system called TREDS-II that has been constructed from COTS components. The TREDS-II system can utilize a combination of Laser Induced Breakdown (LIBS), Townsend Effect Plasma Spectroscopy (TEPS) and Raman spectroscopy techniques with chemometric algorithms to detect hazardous materials. Using these techniques, the TREDS-II system has been successfully applied to the real-time point detection of explosive residues in simulated checkpoint scenarios. The detection capabilities have been extended to CBRN threats, which are presented here.

System performance of surface detection of a variety of CBRNE materials is shown. An overview of improvements to the explosives detection capabilities is given first. Challenges to sensing some specific CBRN threats are then discussed, along with the initial testing of TREDS II on CBRN surrogates on a limited number of surfaces. Signal processing using chemometric algorithms are shown as a demonstration of the system's capabilities. A path forward for using the specific technologies is also provided, as well as a discussion of the advantages that each technology brings to the CBRNE detection effort.

7665-34, Session 7

Laser-induced breakdown plasma-based sensors

S. T. Griffin, The Univ. of Memphis (United States)

Laser Induced Breakdown Spectroscopy (LIBS) is dependent on the interaction between the initiating Laser sequence, the sampled material and the intermediate plasma states. Pulse shaping and timing have been empirically demonstrated to have significant impact on the signal available for active/passive detection and identification. The transient nature of empirical LIBS work makes data collection for optimization an expensive process. Guidance from effective computer simulation represents an alternative. This computational method for CBRNE sensing applications models the Laser, material and plasma interaction for the purpose of performance prediction and enhancement. This paper emphasizes the aspects of light, plasma, and material interaction relevant to portable sensor development for LIBS. The modeling structure emphasizes energy balances and empirical fit descriptions with limited detailed-balance and finite element approaches where required. Dusty plasma from partially decomposed material sample interaction with pulse dynamics is considered. This heuristic is used to reduce run times and computer loads. Computer simulations and some data for validation

are presented. A new University of Memphis HPC/super-computer (~15 TFLOPS) used to enhance simulation. Results coordinated with related effort at Arkansas State University. Implications for ongoing empirical work are presented with special attention paid to the application of compressive sensing for signal processing, feature extraction, and classification.

7665-35, Session 7

Photo-acoustic spectroscopy for trace vapor detection and molecular discrimination

E. L. Holthoff, J. S. Bender, P. M. Pellegrino, U.S. Army Research Lab. (United States); N. Stoffel, A. Fisher, Infotonics Technology Ctr. (United States)

Photoacoustic spectroscopy (PAS) is a useful monitoring technique that is well suited for trace gas detection. This method routinely exhibits detection limits at the parts-per-million (ppm) or parts-per-billion (ppb) level for gaseous samples. PAS also possesses favorable detection characteristics when the system dimensions are scaled to a micro-system design. Current research utilizes quantum cascade lasers (QCLs) in combination with micro-electromechanical systems (MEMS)-scale photoacoustic cell designs. This sensing platform has provided favorable detection limits for a standard nerve agent simulant. The objective of the present work is to demonstrate an extremely versatile MEMS-scale photoacoustic sensor system that is able to discriminate between different analytes of interest.

7665-36, Session 7

Detection of toxic industrial chemicals in water supplies using surface-enhanced Raman spectroscopy

K. M. Spencer, J. M. Sylvia, S. A. Spencer, S. L. Clauson, EIC Labs., Inc. (United States)

Homeland Security places significant importance on ensuring drinking water integrity. Beyond terrorism, accidental supply contamination from a spill or chemical residual increases is a concern. A prominent class of toxic industrial chemicals (TICs) is pesticides, which are prevalent in agricultural use and can be very toxic in minute concentrations. Detection of TICs or warfare agents must be aggressive; the contaminant needs to be rapidly detected and identified to enable isolation and remediation of the contaminated water while continuing a clean water supply for the population. Awaiting laboratory analysis is unacceptable as delay in identification and remediation increases the likelihood of infection. Therefore, a portable or on-line water quality sensor is required that can produce rapid results. In this presentation, Surface-Enhanced Raman Spectroscopy (SERS) is discussed as a viable fieldable sensor that can be immersed directly into the water supply and can provide results in <5 minutes from the time the instrument is turned on until analysis is complete. The ability of SERS to detect several chemical warfare agent degradation products, simulants and toxic industrial chemicals in distilled water, tap water and untreated water will be shown. Spectra demonstrating identification of the pesticides methyl parathion, paraquat and 2,4,5-trichlorophenol down to 1 ppb will be shown. In addition, results for chemical warfare agent degradation products and simulants will be presented. Receiver operator characteristic (ROC) curves, linearity range, reproducibility and other analytical figures of merit will be presented.

7665-37, Session 7

STIRAP on sodium gas as a function of argon buffer gas pressure

J. B. Johnson, S. D. Allen, J. L. Hicks, J. Burdin, Arkansas State Univ. (United States)

The standoff detection of energetic materials via laser induced fluorescence of vapors has received relatively little attention due to spectrally broad fluorescence emission from aerosols and unwanted background molecules. This unwanted broad emission can obscure fluorescence from the molecule of interest. When multiphoton excitation is used, the problem can be avoided by blue-shifting the emission from the target molecule relative to the unwanted broad emission. As a precursor to the detection of explosives, we demonstrate coherent multiphoton excitation via STIRAP on sodium vapor in an argon buffer gas as a function of argon pressure. Results indicate that STIRAP can be performed in a buffer gas at atmospheric pressure with a minimal reduction in STIRAP efficiency. The 15 ps long light pulses used for the pump and Stokes pulses were produced by two synchronously pumped OPO/OPAs tuned to the 3p (2P1/2)   3s (2S1/2) transition for the pump pulse and the 5s (2S1/2)   3p (2P1/2) for the Stokes pulse.

7665-38, Session 7

CATSI EDM: a new sensor for the real-time passive standoff detection and identification of chemicals

J. Thériault, Defense Research Establishment Valcartier (Canada); P. Lacasse, AEREX avionique inc. (Canada); H. Lavoie, F. Bouffard, Defense Research Establishment Valcartier (Canada); Y. Montembeault, V. Farley, P. Lagueux, M. Chamberland, Telops (Canada)

DRDC Valcartier recently completed the development of the CATSI EDM (Compact Atmospheric Sounding Interferometer Engineering Development Model) for the Canadian Forces (CF). It is a militarized sensor designed to meet the needs of the CF in area surveillance capabilities for the detection and identification of chemical warfare agents (CWA) and toxic industrial chemicals (TIC). The sensor hardware and software were developed under contract by Telops while DRDC Valcartier was responsible for contract management, algorithm development and final system performance and evaluation testing.

CATSI EDM is a passive infrared double-beam Fourier spectrometer system designed for real-time stand-off detection and identification of chemical vapours at distances up to 5 km. It is based on the successful passive differential detection technology developed and demonstrated by DRDC Valcartier from 1996 to 2003. The sensor advantageously combines well balanced dual-beam FTIR interferometer outputs with two adjacent field of view to optically suppress the spectral background and the instrument self emission spectrum. This technique known as optical subtraction, results in a target gas spectrum which is almost free of background, thus making possible detection of weak infrared emission in strong background emission.

CATSI EDM consists of an optical head mounted on a pan and tilt tripod, a control and processing computer with an integrated local console, a remote console, batteries, cables and power conversion sources. This paper summarizes the system requirements, achievements, hardware and software characteristics and test results.

7665-39, Session 7

First field-trial results of the MR-CATSI dual-input beam spectroradiometer for the standoff detection of chemicals

L. M. Moreau, ABB Inc. (Canada); E. Puckrin, C. S. Turcotte, J. Thériault, Defense Research Establishment Valcartier (Canada); C. A. Vallieres, C. B. Roy, ABB Inc. (Canada)

The MR-CATSI combines the latest ABB Bomem MR spectro-radiometer technology and software with the concepts used in the design of the ABB and DRDC CATSI instrument twelve years ago.

This instrument is a Fourier transform spectro-radiometer with dual input beams. It is a passive, stand-off sensor. One input port can be directed to the area to be interrogated while the other input beam can be pointed at the background. The instrument automatically measures the difference of spectral radiance between the target and the background, hence achieving a suppression of the background signal. The resulting measurement is the unique spectral signature of the target.

The system includes a software module to control the instrument and the acquisition parameters, a module for the radiometric calibration and a module to perform the identification and quantification, in real time, of various gases.

Overview of the design and results from field trials will be presented. This includes recent measurements of a number of gas plumes, including mixtures with overlapping spectral bands, and measurements from spilled chemical powders.

7665-40, Session 8

FTIR gas analysis with improved sensitivity and selectivity for CWA and TIC detection

C. M. Phillips, H. Tan, MKS Instruments (United States)

This presentation describes the use of an FTIR (Fourier Transform Infrared)-based spectrometer designed to continuously monitor ambient air for the presence of chemical warfare agents (CWAs) and toxic industrial chemicals (TICs). The necessity of a reliable system capable of quickly and accurately detecting very low levels of CWAs and TICs while simultaneously retaining a negligible false alarm rate will be explored.

Technological advancements in FTIR sensing have reduced noise while increasing selectivity and speed of detection. These novel analyzer design characteristics are discussed in detail and descriptions are provided which show how optical throughput, gas cell form factor, and detector response are optimized. The hardware and algorithms described here will explain why this FTIR system is very effective for the simultaneous detection and speciation of a wide variety of toxic compounds at ppb concentrations. Analytical test data will be reviewed demonstrating the system's sensitivity to and selectivity for specific CWAs and TICs; this will include recent data acquired as part of the DHS ARFCAM project. These results include analyses of the data from live agent testing for the determination of CWA detection limits, immunity to interferences, detection times, residual noise analysis and false alarm rates. Sensing systems such as this are critical for effective chemical hazard identification which is directly relevant to the CBRNE community.

7665-41, Session 8

Airborne infrared-hyperspectral mapping for detection of gaseous and solid targets

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Airborne hyperspectral ground mapping is being used in an ever-increasing extent for numerous applications in the military, geology and environmental fields. The different regions of the electromagnetic spectrum help produce information of differing nature. The visible, near-infrared and short-wave infrared radiation (400 nm to 2.5 μm) has been mostly used to analyze reflected solar light, while the mid-wave (3 to 5 μm) and long-wave (8 to 12 μm or thermal) infrared senses the self-emission of molecules directly, enabling the acquisition of data during night time.

The Telops Hyper-Cam is a rugged and compact infrared hyperspectral imager based on the Fourier-transform technology. It has been used on the ground in several field campaigns, including the demonstration of standoff chemical agent detection. More recently, the Hyper-Cam has been integrated into an airplane to provide airborne measurement capabilities. The technology offers fine spectral resolution (up to 0.25 cm-1) and high accuracy radiometric calibration (better than 1 degree Celsius). Furthermore, the spectral resolution, spatial resolution, swath width, integration time and sensitivity are all flexible parameters that can be selected and optimized to best address the specific objectives of each mission.

The system performance and a few measurements have been presented in previous publications. This paper focuses on analyzing additional measurements in which detection of fertilizer and Freon gas has been demonstrated. This paper also includes a detailed analysis of the Hyper-Cam airborne measurement sensitivity.

7665-42, Session 8

Imaging open-path Fourier transform infrared spectrometer for 3D cloud profiling

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OPTRA is developing an imaging open-path Fourier transform infrared (I-OP-FTIR) spectrometer for 3D profiling of chemical and biological agent simulant plumes released into test ranges and chambers. An array of I-OP-FTIR instruments positioned around the perimeter of the test site, in concert with advanced spectroscopic algorithms, enables real time tomographic reconstruction of the plume. The approach is intended as a referee measurement for test ranges and chambers. This Small Business Technology Transfer (STTR) effort combines the instrumentation and spectroscopic capabilities of OPTRA, Inc. with the computed tomographic expertise of the University of North Carolina, Chapel Hill.

In this paper, we summarize the design and build and detail system characterization and test of a prototype I-OP-FTIR instrument. System characterization includes radiometric performance and spectral resolution. Results from a tomographic reconstruction of sulfur hexafluoride and ethylene plumes in a laboratory setting are also presented.

7665-43, Session 8

Measurement of ammonia skin gas using a mid-infrared QCL

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Evidentiary use of exhaled breath is now a common forensic method for assessing driver impairment due to alcohol exposure. Studies conducted by the US EPA have suggested exhaled biomarkers can also be used to assess the routes and magnitude of human exposure to environmental toxins. The extension to threat agents is a natural one and may include not only assessing the exposure of victims, but also as a screening tool to identify people with malicious intent. Several recent studies have reported that the amount of excreted skin gas, for certain compounds such as ammonia, correlate with that in the breath.

In fact, the concentration of ammonia excreted through human skin has recently been measured using GC-FID by a group from Nagoya, Japan. These emissions, referred to as ammonia skin gas, were determined to be 1.7±.4 ng/cm3 for healthy subjects in the study. To achieve greater molecule specificity, sensitivity, as well as add a real time capability, we are investigating the potential of a mid IR laser spectrometer, consisting of an external cavity QCL coupled with a low volume 75 meter Herriott gas sample cell, to perform real time sensing measurements. Here we will present a series of ammonia skin gas measurements obtained with this mid IR laser system.

7665-44, Session 8

A non-negative matrix factorization algorithm for the detection of chemicals from an incomplete Raman library

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Raman spectroscopy has proven to be a powerful technique for the standoff identification of surface-deposited chemical agents. In the supervised detection framework, the measured Raman spectrum is compared to a reference library of known spectra. A well-known shortcoming of the supervised approach is that no comprehensive library exists, and when chemicals are present that are not contained in the reference library, the supervised algorithms may confuse those chemicals with library members.

One way to deal with this problem is to use an unsupervised method such as nonnegative matrix factorization (NMF) to estimate both the constituent spectra and their relative quantities directly from a block of measured spectra. Chemical identification may then be performed by associating the extracted spectra with the reference library spectra. We show that this two-stage NMF approach fails if there is insufficient variation in the data; this happens because knowledge of the reference library was not used in extracting the spectra.

We present a novel modification of NMF in which a subset of the extracted spectra are constrained to be equal to the known reference library. This method is shown to outperform the standard NMF approach and the common supervised identification algorithms when there are chemicals present that are not in the library. This algorithm is applicable to any problem in which a target is identified by comparing a block of measured data to a library of known constituent signatures.

7665-45, Session 8

Joint-services lightweight standoff chemical agent detector reduced field-of-view

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A reduced Instantaneous Field of View (IFOV) Fourier Transform Infrared (FTIR) system for standoff detection of chemical agents demonstrated improved detection at range during the Chemical / Biological Distributed Early Warning System (CBDEWS) testing in Oct '08 and May '09. The reduced IFOV system, from the original design parameter of 1.5 degree (27 millradians) to 0.5 degrees (9 millradians), includes novel modifications to the scanner assembly optical design to reduce the FOV without sacrificing existing radiometric sensitivity performance. The design modifications also allow for a straightforward retrofit of existing Joint Services Lightweight Standoff Chemical Agent Detectors (JSLSCAD). This paper will deliver an overview of the design and test results from field trials of the system as a function of range and environmental conditions.

7665-46, Session 8

Improved Raman detection using polarization analysis

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Raman spectroscopy is a very powerful technique for molecular identification, and small Raman instruments have been used successfully to identify toxic substances. The sensitivity of the technique, however, can be limited by fluorescence interference arising from the analyte itself or sample impurities. In the case of surface detection, the Raman signature and/or fluorescence from the surface can also interfere with identification of the target chemical. We take advantage of the polarization characteristics of the Raman scattering to improve the sensitivity and reduce the broadband fluorescence background. We demonstrated the use of polarization information inherent in the Raman scattering of chemicals to provide improved signal to noise and signal to background Raman spectra with both UV and NIR excitation.

Using a custom fiber optic probe, we have also demonstrated real-time polarization analysis. In this case, the parallel and perpendicular polarization components of the Raman signal are separated and directed to the inputs of different fibers whose output ends are stacked vertically at the spectrograph input. Consequently, the spectrum dispersed onto the charge coupled device (CCD) detector has the parallel and perpendicular components separated vertically. By binning vertical pixels into two rows, parallel and perpendicular polarization spectra are measured and subtracted or divided in real-time.

7665-47, Session 8

Proximal detection of chemical warfare agents using PMIRRAS

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Non-contact chemical warfare agent detection has been demonstrated on military painted surfaces using polarization modulation infrared reflection-absorption spectroscopy (PMIRRAS). Notably VX has been detected on chemical agent resistance coating (CARC) paint at a distance of approximately 10 cm. PMIRRAS does not rely on the presence of chemical vapours and is not effected by many common battlefield interferants such as aerosolized dust, water and diesel vapours, etc., making it highly suitable for use in operational environments. Theoretical ab initio calculations carried out at the B3LYP/6-31G(d,p) level of theory and basis set have been used to understand the presence upward-oriented and downward-oriented PMIRRAS absorption features in terms of molecular orientation at a surface and the orientation of the dipole derivative vector of a given vibrational mode.

7665-48, Session 8

Detection of chemicals in mixed, two-dimensional Raman spectra

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Recently, researchers at the Naval Research Laboratory have developed the SWORrD system [1,2] for measuring two-dimensional Raman Spectra. The device consists of a tunable ultraviolet laser that illuminates the sample at various wavelengths (210-300 nm) and collects a single Raman spectrum at each laser wavelength. The single spectra are combined to form a two-dimensional spectrum (laser wavelength by scattered wavenumber).

In this paper we introduce a novel method for the detection of known agents ('targets') within measured 2d spectra. Our method is bases on 'linear mixed pixel' techniques from hyperspectral imagery; in particular, we generalize the Adaptive Subspace Detector (ASD) [3] to a form suitable for SWORrD samples. Our detector uses the individual laser runs to define a set of points within wavenumber space; the set of points corresponding to a 2d spectra defines a particular subspace that contains each material. These subspaces are then used with ASD to identify targets. We include experimental results using both synthetic and real-world data to illustrate our results.

1. J. Grun, et. al. "Identification of bacteria from two-dimensional resonant-Raman spectra", Analytical Chemistry 79 (14) 2007

2. G. Comanescu, et al. "Identification of explosives with two-dimensional ultraviolet resonance Raman spectroscopy", Applied Spectroscopy 62 (8) 2008

3. D. Manolakis and G. Shaw, "Detection algorithms for hyperspectral imaging applications", IEEE Sig Proc Mag 19 (1), 2002

7665-49, Session 10

A two-pixel Compton imager

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We are designing a Compton imager for use in security investigations and in incident remediation. Previously, results from simulations of a system consisting of several layers of pixellated solid scintillator for both the scatter and absorber detectors were reported. We have now established a two-pixel test stand for validation of the simulations. The stand consists of a single scatter pixel fixed in space, and a single absorber pixel affixed to a two-dimensional translator. Automated translation of the absorber pixel to different positions allows for the acquisition of data at multiple Compton scattering angles, thereby building up a dataset from a mock multi-channel Compton imager. Different candidate scintillating materials have been tested and the angular resolution, detection efficiency, and time required to achieve source localization for these mock imagers are presented.

7665-51, Session 10

Thermal neutron detectors based on gadolinium-containing lanthanide-halide nanoscintillators

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No abstract available

7665-52, Session 10

Radiation-induced failures and degradation of wireless real-time dosimeter under high-dose-rate irradiation

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When a radiological threat such as a dirty bomb or radiological dispersal device are triggered, we need to search for the source position of radiological and nuclear material and to identify the region of radioactive contamination. We are developing a wireless real-time dosimeter for the first responder. These apparatus are composed of semiconductor devices. However, the operation of semiconductor devices under high-dose-rate irradiation has not yet been sufficiently evaluated.

Here we describe the radiation induced failures and degradation of semiconductor devices in operating and storage condition. The radiation effects (cumulative effects and single event effects) on wireless network devices (303MHz and 2.4GHz) and low power AVR microcontrollers (Atmel) are evaluated under an irradiation over 3Gy/h,10Gy/h and 100Gy/h. The limitations of these devices are discussed. Also we describe the development for the portal radiation monitors with Distributed Sensor Network.

7665-53, Session 10

Development of capacitive Gamma-radiation detector utilizing liquid crystal

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Radiation detectors and dosimeters are critical for current and future manned mission in security, defense and space applications. In this effort, the author has developed a liquid crystal (LC)-based capacitive gamma radiation detector and dosimeter. This innovation will transduce the gamma radiation dose into a measurable capacitive quantity via tracking the LC deformation. The proposed mechanism replaces the present optical transduction in LC-based detectors, and offers several remarkable advantages over the optical method. It provides greater insight into the fundamental distortion occurring in the LC film due to the presence of the gamma radiation, and offers the ability to identify and track the average deformation. It also does not require visual inspection and consumes little power which makes it ideal for a remotely deployable sensor. In addition, the removal of the optical transparency requirement of the substrate allows for a broader class of substrate selection.

The LC detectors exploit the molecular orientational behavior. Due to the collective behavior of the molecules forming LCs, minor changes in the molecular orientation caused by exposing the LC film to gamma radiation can be amplified into a significant change in the director field of the LC. The proposed detector has been irradiated with different gamma doses, and the LC film has responded differently (different director axis orientations and/or different degrees of ordering) to each dose. Consequently, the capacitance was varied and these variations were measured. Therefore, this detector has proven a capability to transducing the gamma radiation dose into a measurable capacitive quantity. In addition, a simpler system with autonomous operation and reduced possible false alarms is achievable.

7665-54, Session 10

A radiation scintillator embedded with a converting medium to detect and discriminate the four species of ionizing radiation

S. M. Pellegrin, C. G. Wilson, Louisiana Tech Univ. (United States)

Summary: A new nanoparticle loaded plastic scintillator embedded in a glass substrate detects and discriminates all species of radiation emitted from fissionable bomb making materials. The fast electron scintillating resin is doped with tailored charge conversion nanoparticles to produce characteristic optical pulses. The created optical pulses exit the detector, since the nanoparticles are appreciably smaller than the wavelength of light. Microsandblasting is used to etch deep cavities in the glass substrate forming independent optical paths. The doped resin is injected into the cavities and cured. A separate off the shelf PM tube linearly amplifies the created light pulse into a usable electrical signal. By using tailored nanoparticles, the physical mechanisms for converting different species of radiation into lower energy electrons allows for pulse height spectroscopy to discriminate between alpha, beta, gamma, and neutron radiation.

Results: A 36Cl source was used to test the beta detector, which is loaded with W. The drop in count rates versus distance was found to be similar to traditional detectors. The gamma detector loaded with Pb nanoparticles was tested with a 60Co source. The addition of Pb provided greater sensitivity to the gamma radiation. An 241Am source was used to test the glass doped scintillator. The count rates remained fairly constant for varying distances since alpha particles tend to travel in straight paths until losing most of their initial energy. The 157Gd loaded scintillator was tested with an Am/Be source. 157Gd has the largest thermal neutron absorption cross section at 255,000 barns and releases a usable characteristic 72keV electron in 39% of the capture reactions.

7665-55, Session 10

Design of dual-road transportable portal monitoring system for visible light and gamma-ray imaging

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The use of radiation sensors as portal monitors is increasing due to heightened concerns over the smuggling of fissile material. Transportable systems that can detect significant quantities of fissile material that might be present in vehicular traffic are of particular interest, especially if they can be rapidly deployed to different locations. To serve this application, we have constructed a rapid-deployment portal monitor that use visible-light and gamma-ray imaging to allow simultaneous monitoring of multiple lanes of traffic from the side of a roadway. The system operation consists of using machine vision methods to detect vehicles as they enter and exit the field of view and estimate their position in each frame. The cameras are synchronized to both sides of the road and to a gamma imaging system which allows the gamma-ray imager to harvest gamma-ray data specific to each vehicle, integrating its radiation signature for the entire time that it is in the field of view. Thus our system creates vehicle-specific radiation signatures and avoids source confusion problems that plague non-imaging approaches to the same problem. Our current prototype instrument under development was designed for measurement of five lanes of freeway traffic. Stereoscopic cameras are used with a third "alignment" camera for motion compensation and are mounted on a 50' deployable mast. In this paper we discuss the design considerations for the machine vision system, the algorithms used for vehicle detection and position estimates, and the overall architecture of the system. We also discuss system calibration for rapid deployment. Finally we show performance metrics of the system to date under testing conditions.

7665-56, Session 10

Detectors to characterize an intense, pulsed source of gamma-rays and neutrons resulting from associated photofission

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A single, intense pulse of high-energy gamma-rays is used to induce photo fission in fissionable material. Measurement of the neutrons associated with these photo fissions can be used to confirm the presence of the material. A pinch-reflex ion diode produces a proton beam with a 4 MV peak voltage, 80 kA peak current, and 50 ns FWHM pulse width. This beam is directed onto a PTFE (CF2) target to generate an intense pulse of 6 to 7 MeV characteristic gamma-rays via the 19F(p,alpha gamma)16O reaction. A suite of detectors is used to characterize the ion diode, the characteristic gamma-rays, and the neutron emissions induced by the gamma-rays in depleted uranium (DU). The time dependence and relative intensity of the characteristic gamma-ray pulse is measured with a plastic scintillator coupled to a photomultiplier tube (PMT). Unintentional neutron emission is associated with the normal operation of the ion diode. Two other plastic scintillator/PMT detectors are used in combination as a neutron time-of-flight spectrometer to determine the energy of these neutrons. The total number per pulse of these unintentionally-produced neutrons is measured using a rhodium-foil activation counter. The ion diode also emits bremsstrahlung with a 4 MeV endpoint energy (too low to induce photo fission). The angular distribution of the dose associated with this bremsstrahlung is measured with an array of CaF2 thermoluminescent dosimeters. Finally, a 6Li-loaded glass scintillator detector is used to search for delayed neutrons generated by photo-nuclear processes in the irradiated DU.

7665-57, Session 10

SmartID: a highly accurate physics-based isotope attribution algorithm

M. J. Harrison, R. S. Detwiler, G. E. Sjoden, Univ. of Florida (United States)

The spectral post-processing algorithm Advanced Synthetically Enhanced Detector Resolution Algorithm (ASEDRA) has shown to be a powerful tool for deconvolving full energy peaks from scintillation spectrometer-acquired gamma-ray spectra, effectively improving obtainable data-synthesized energy resolutions by a factor of four to six times over what is rendered from the detector. An isotope attribution algorithm, SmartID, was developed to augment ASEDRA in order to improve radionuclide identification accuracy. SmartID utilizes a novel, physics-based method of importance weighting the ASEDRA-identified peaks and the emissions of a candidate isotope. This methodology augments screening potential false peaks and prevents isotope mismatches. As a final step, SmartID assigns a physical matching attribution score to each possible isotope match to reflect the goodness of fit between the isotope and the ASEDRA-identified peaks. A test suite of 105 gamma-ray spectra acquired with a 2"x2" NaI:Tl spectrometer under varying shielding conditions and various single and multi-source configurations were recorded for testing the accuracy of ASEDRA+SmartID. The sources utilized in the tests included 133Ba, 109Cd, 57Co, 60Co, 137Cs, 152Eu, 54Mn, 22Na, 232Th, natural uranium rods and a PuBe source. Shielding configurations tested between the source(s) and detector included no shielding, a 0.635 cm steel plate and Pb sheets of thicknesses 0.5, 1.0, 1.7 and 2.5 cm in various combinations. Further, a large Ni shield equivalent to 7 mean-free-paths was utilized to heavily shield the PuBe source. Overall, SmartID coupled with ASEDRA proved to be more than 95% accurate in attributing the correct isotope(s) to the spectra.

7665-61, Session 10

Development of low-power wireless networked radioactive material sensor array

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This paper will describe the design and development of a low-power, compact, wireless-networked radiation sensor array. The sensor system was developed for event detection and remote warning for a broad range of radioactive materials. The radiation detector is presently based on photomultiplier tubes (PMT) coupled to Bismuth Germanium Oxide (BGO) scintillators. The detectable energy range is set for operation from 100keV to 2MeV photon energies. The sensitivity is demonstrated by the detection of a 1µC Cs-137 source at a distance of at least 3m. The circuit designed to maximize sensitivity connects the PMT detectors through a high-gain analog amplifier and absolute comparator. The data event is then broadcast over the IEEE 802.15.4 network. This network protocol was chosen to take advantage of low-power connectivity and ability to connect a large number of devices into a single network. Low power design is used throughout the system to allow for long-life battery operation of the PMT, amplifiers, and wireless interface. The largest component is the 3x3" BGO crystal. The development work also involved the creation of software to provide the ability to timestamp and quantify the radiation intensity. The location of radioactive sources is triangulated using data capture software written in MATLAB. A system composed of 4 detectors is currently implemented in our radiation facility in order to track the transport of radioisotopes throughout the facility. The networked array operates well as a facility system however the architecture is designed to be operated outside the laboratory environment as well. The facility radiation safety implementation is described performance compared to commercial sensors.

Conference 7666: Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense IX

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7666-01, Session 1

Cyber security: state of art and challenges

P. K. Khosla, Carnegie Mellon Univ. (United States)

No abstract available

7666-02, Session 1

Denial of service (DoS) attack and mitigation in IEEE 802.11 networks

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With the advances in wireless technology, the IEEE 802.11 wireless Local Area Network (WLAN) becomes one of the prevalent technologies. However, the IEEE 802.11b/g wireless network uses the frequency of unlicensed 2.4GHz, which makes the network much more vulnerable than their wired counterparts. Denial of Service (DoS) is such an easy attack which can be launched by an inexperienced attacker, but may cause significant system performance degradation, or even network partition and failure. In this paper, we present several attack detection and mitigation mechanisms. Through a set of experiments and simulations, we show the effectiveness of proposed DoS mitigation strategies.

7666-03, Session 1

Hypergame theory applied to cyber attack and defense

J. T. House, G. Cybenko, Dartmouth College (United States)

Primary topical area: Cybercrimes and Cyberterrorism Technologies and Systems

This work concerns cyber attack and defense in the context of game theory -- specifically hypergame theory. Hypergame theory extends classical game theory with the ability to deal with differences in players' expertise, differences in their understanding of game rules, misperceptions, and so forth. Each of these different sub-scenarios, or subgames, is associated with a probability -- representing the likelihood that the given subgame is truly "in play" at a given moment. In order to form an optimal attack or defense policy, these probabilities must be learned if they're not known a-priori.

I present Hidden Markov Model and Maximum Entropy methods for accurately learning these probabilities through multiple iterations of both normal and modified game play. I also present a widely-applicable approach for the analysis of cases where an opponent is aware that he is being studied, and intentionally tries to spoil the process of learning and obfuscate his attributes.

These are considered in the context of a generic, abstract cyber attack example. I show that machine learning efficacy is heavily dependent on the goals and styles of participant behavior -- e.g. does our opponent seek the most effective attack / defense, or is this perhaps a series of information-gathering probes? Do we place a higher premium on learning or on defense? To this end detailed simulation results under various combinations of attacker and defender behaviors are presented and analyzed. I also discuss the application of these methods to other scenarios.

7666-04, Session 1

Using PCA for selecting network behavioral anomaly metrics

V. H. Berk, I. Gregorio-de Souza, Dartmouth College (United States); A. V. Barsamian, ProQueSys, LLC (United States)

This work addresses new approaches to behavioral analysis of networks and hosts for the purposes of security monitoring and anomaly detection. Most commonly used approaches simply implement anomaly detectors for one, or a few, simple metrics and those metrics can exhibit unacceptable false alarm rates. For instance, the anomaly of network communication is defined as the reciprocal of the likelihood that a given host uses a particular protocol (or destination) may result in an unrealistically high threshold for alerting to avoid being flooded by false positives.

We demonstrate that selecting and adapting the metrics and thresholds, on a host-by-host, or protocol-by-protocol basis, can be done by established multivariate analyses, such as PCA.

We show how to determine one or more metrics, for each network host, that records the highest available amount of information regarding the baseline behavior, and shows relevant deviances reliably.

We describe the methodology used to pick from a large selection of available metrics, and illustrate a method for comparing the resulting classifiers.

Using our approach we are able to reduce the resources required to properly identify misbehaving hosts, protocols, or networks, by dedicating system resources to only those metrics that actually matter in detecting network deviations.

7666-05, Session 1

Dynamic social network analysis using conversational dynamics in social networking and microblogging environments

G. F. Stocco, R. Savell, G. V. Cybenko, Dartmouth College (United States)

In many signal intelligence collection contexts, the textual content of communications may be unavailable. In these instances, it is often desirable to infer the status of the network and its component entities from patterns of communication flow. Conversational dynamics among entities in the network may provide insight into important aspects of the underlying social network such as the formational dynamics of group structures, the active state of these groups, individuals' roles within groups, and the likelihood of individual participation in conversations. To gain insight into the use of conversational dynamics to facilitate Dynamic Social Network Analysis, we explore the predictive value of conversational processes among entities in a social networking and micro-blogging environment such as Twitter. Specifically, we attempt to identify, classify, and track active social groups, as well as to predict future patterns of topic propagation, network participation, and social role formation via analysis of these processes.

Conference 7666: Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense IX

SPIE Defense, Security+Sensing

7666-06, Session 1

Effectively identifying user profiles in network and host metrics

V. H. Berk, J. P. Murphy, I. Gregorio-de Souza, Dartmouth College (United States)

This work presents a collection of methods that is used to effectively identify users of computers systems based on their particular usage of the software and the network. Not only are we able to identify individual computer users by their behavioral patterns, we are also able to detect significant deviations in their typical computer usage over time, or compared to a group of their peers. For instance, most people have a small, and relatively unique selection of regularly visited websites, certain email services, daily work hours, and typical preferred applications for mandated tasks. We argue that these habitual patterns are sufficiently specific to identify fully anonymized network users.

We demonstrate that with only a modest data collection capability, profiles of individual computer users can be constructed so as to uniquely identify a profiled user from among their peers. As time progresses and habits or circumstances change, the methods presented update each profile so that changes in user behavior can be reliably detected over both abrupt and gradual time frames, without losing the ability to identify the profiled user.

The primary benefit of our methodology allows one to efficiently detect deviant behaviors, such as subverted user accounts, or oganizational policy violations. Thanks to the relative robustness, these techniques can be used in scenarios with very diverse data collection capabilities, and data privacy requirements.

In addition to behavioral change detection, the generated profiles can also be compared against pre-defined examples of known adversarial patterns.

7666-07, Session 2

Comparison of experimental and mathematical models of attenuation and dispersion for co-propagating helical channels of same wavelength in optical fibers

S. H. Murshid, A. Chakravarty, Florida Institute of Technology (United States)

Spatial reuse of optical frequencies in optical fibers is possible through a novel Spatial Domain Multiplexing (SDM) technique that enables simultaneous propagation of two or more spatially multiplexed channels of exactly the same wavelength by confining them to unique spatial locations inside the fiber. Spatial filtering techniques are employed at the output end to separate the individual optical channels. The SDM channels follow helical path inside the carrier fiber and do not interfere with each other. This paper presents electromagnetic wave based model to analyze two such co-propagating SDM channels and then compares the model predictions to experimental data. The comparison of attenuation, dispersion and beam profiles show a close match to prove that SDM technique can be used to enhance the bandwidth of optical fiber systems.

7666-08, Session 2

Effect of atmosphere on free-space optical communication networks for border patrol

J. W. Zeller, T. Manzur, Naval Undersea Warfare Ctr. (United States)

We investigate Free-Space Optical (FSO) communication links for relaying video from visible to MWIR cameras at strategic positions along US borders to identify potential threats and protect national interests as part of the Homeland Security effort. Through MODTRAN-based modeling of transmission bands across the visible to MWIR spectrum for multiple elevation angles in atmospheric conditions including Navy maritime, desert extinction, and various levels of rain and fog, we determine which wavelength ranges are the most practical for minimizing transmission losses for both ideal and unfavorable conditions. The atmospheric, free-space, and scintillation losses are calculated for the various FSO configurations and atmospheric conditions to determine incident beam power required for successful data transmission. These theoretical results are to be compared with experimental data from a 1 km FSO link test at NUWC with a horizontal path at a height of 4 ft above the surface. Using advanced tunable laser sources to provide illumination across wavelength ranges from visible to MWIR, it should be possible to overcome transmission limitations associated with adverse weather and atmospheric conditions for communication networks to enhance the protection of our borders.

7666-09, Session 2

CAD simulated and experimental beam profile analysis of single-mode tapered fibers for optical bandwidth enhancement applications

S. H. Murshid, A. Chakravarty, R. Biswas, Florida Institute of Technology (United States)

Most developments in data transfer techniques are incremental by nature and the goal of increasing total capacity in optical communications and networking requires new concepts for basic transmission media. The transmission data rates can only be enhanced by introducing new modulation and multiplexing techniques. In this paper different single mode tapered fiber waveguides are used to design a Spatial Multiplexer Unit (SMU) for a novel optical fiber multiplexing technique called the Spatial Domain Multiplexing (SDM) that allows co-propagation of two or more channels of exactly same wavelength without interfering with each other. This paper also presents a CAD model for the SMU and then compares the output beam profiles from different single mode tapered fibers to determine the optimum geometry for the SMU. Finally experimental and simulated beam profiles for the SMU are presented.

Keywords:Communication; Optical Multiplexing; Bandwidth Enhancement; CAD Model; Fiber Taper Technique;Beam Profile.

7666-10, Session 3

Next-generation NLWs versus current joint-NL capability gaps

D. B. Law, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-11, Session 3

FY10 NL technology thrust areas for S&T

J. Keenan, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-12, Session 3

NL human effects and effectiveness processes

A. Barrett, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

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7666-13, Session 3

NL vehicle stopping technology status

S. Griffiths, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-14, Session 3

NL vessel stopping technology status

S. Griffiths, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-15, Session 3

Optical/acoustic: combine effects for hail/warn/incapacitation

R. I. Scott, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-16, Session 3

NL counter-swimmer (underwater acoustic human effects)

W. Bergei, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-17, Session 3

Next-generation active denial technologies

R. I. Scott, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-18, Session 3

Human electro-muscular incapacitation hardware/bio-effects status

W. Bergei, Joint Non-Lethal Weapons Directorate (United States)

No abstract available

7666-19, Session 4

Command and control in homeland security

D. G. Boyd, U.S. Dept. of Homeland Security (United States)

No abstract available

7666-20, Session 4

Situational awareness and informed decision-making for law enforcement responders

G. C. Tillery, National Institute of Justice (United States)

No abstract available

7666-21, Session 4

Structure mapping for improved situational awareness, missions planning, and operator tracking

J. Morrison, W. Calcutt, M. Reese, J. Williams, McQ, Inc. (United States); G. J. Roehrich, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

McQ developed for the U.S. Army Armament Research, Development and Engineering Center (ARDEC) an acoustic and infrared measurement, node localization, and building characterization prototype system. The system is designed for both manned and unmanned use to develop greater situational awareness through the exploration of unknown structures and relay of mapping data through ARDEC's Firestorm network. When employed by personnel, the system will map a structure with minimal user intervention and supply floor plans and current location when needed. Data can be immediately relayed to personnel both inside and outside of the building for up-to-date maps and user location. This research covers ultrasonic and infrared ranging sensor performance, GPS-denied positioning solutions, sensor data fusion, and mapping algorithms. Applications of McQ's structure mapping system also include first responder mapping and positioning. Maps generated by the system are useful for both real-time operations and future missions planning. McQ will present development methodology and performance.

7666-22, Session 4

Increasing situation awareness of the CBRNE robot operators

P. Jasiobedzki, H. Ng, M. Bony, MacDonald, Dettwiler and Associates Ltd. (Canada); C. H. McDiarmid, Royal Canadian Mounted Police (Canada)

Initial response to events where use of CBRNE materials is suspected often involves using unmanned robotic platforms. Such platforms are equipped with cameras and detectors selected for specific threats and are teleoperated in the scene providing live data to the operator station. Current systems offer integration of detectors with the on-board robot controller, transmission using the robot comms, display and data logging. If the GPS is available then the data may be geo-located.

Situational awareness of the robot operators is limited, as they rely on live camera views and instrument readings. Creating a map of contamination or compiling measurements taken at different locations or time (without GPS) is a manual process than cannot be carried out during the event. Measurements from various sensors are not registered with the work space or camera views. Access to recent or geo-located data is not provided.

This paper describes a novel operator station for a mobile robot equipped with a CBRNE data acquisition system. This operator station has been developed and integrated with the CBRNE Crime Scene Modeler (C2SM). C2SM operates on-board a mobile robotic platform and acquires data using cameras (visible and Infrared) and a suite of CBRNE detectors. The data is time-stamped geo-located using on-board localization system (GPS independent) and sent in near real-time to the operator station. Operator is provided with multiple screens providing: i) live instrument/camera views, ii) two dimensional (2D) floor/ground map, and iii) three dimensional (3D) models of visited scenes.

The instrument view displays camera images and CBRNE detector data (directional gamma, chemical, air quality and an explosive vapour). All data is logged in a database with time and location of acquisition. Both the 2D and 3D views of the scene contain the current robot location and it's traversed path, objects in the vicinity of the robot, and measurements from the detectors. The user interfaces enable querying the database and displaying measurements of interest. The 2D view is created and updated almost in real time and presents an iconic view of the scene. The 3D view (available with a delay of several minutes due to processing) presents detailed photorealistic views of the scene in 3D.

A unique feature of the developed operator station is an ability to go back in time and observe images and measurements at locations visited earlier and from the same viewpoint. An operator selects a location of interest in the 2D view or a time instance, and the system loads relevant data from the database and displays it in the same instrument view framework. This mode of operation is preferred by responders: the data is available sooner; more iconic 2D representation is quicker to understand, using the same interface layouts for live and past data makes it easier to learn to operate the system. Access to the photorealistic 3D model is still necessary to obtain an immersive view of the scene, perform measurements in 3D, etc.

7666-23, Session 5

Emergency responder location tracking program: technologies and challenges

J. Mapar, U.S. Dept. of Homeland Security (United States)

No abstract available

7666-24, Session 5

Effects of operator spatial ability, shared visual resources, and unmanned vehicle perspective on team performance in a military reconnaissance task

J. R. Keebler, T. Fincannon, S. Ososky, D. Schuster, F. G. Jentsch, Univ. of Central Florida (United States)

Given the burgeoning use of Remotely Operated Vehicles (ROVs) in the field, human-robot teaming is an increasingly relevant area of research. The conditions that maximize performance of operators working within human-robot teams are of particular interest. Research is needed to examine the effectiveness of human teams as they actively operate autonomous and semi-autonomous ROVs. Using a scaled Military Operations in Urban Terrain (MOUT) facility with heterogeneous, autonomous ROVs (UGV and UAV), undergraduate participants were trained to conduct reconnaissance missions in a live simulation.

The study described here investigated performance with the following: spatial ability, vehicle perspective (UAV versus UGV), and shared visual resources (sharing video vs. not sharing video). A main effect was found for UAV operators reporting more targets ($p < .005$) than UGV operators. Also, an interaction was found between shared visual resources and spatial ability. Specifically, participants with high spatial ability reported more targets when they had shared visual resources.

This research suggests the use of spatial ability as a potential selection tool for unmanned vehicle operators. The research also demonstrates that the effects of sharing visual resources are dependent upon the spatial abilities of the individuals within the team.

7666-25, Session 5

Statistical meta-tagging for knowledge discovery in sensor streams

S. R. Sukumar, Oak Ridge National Lab. (United States)

When apriori on the data or the model that generates the data is minimal (either due to lack of domain expertise or randomness of the observed event), what generic parameters of the sensor data stream should one observe and archive to hypothesize concept drift and flag anomalies? How do we formulate such generic data features to also capture the salient and informative aspects of the data stream?

We propose a statistical meta-tagging framework that creates a middleware of query able feature descriptors. The formulation of such a framework in our current implementation focuses on Fourier, Wavelet-

basis and the Hilbert spectrum. In the Fourier spectrum the signal is expressed as a sum of periodic sinusoids. Multi-resolution wavelet decomposition represents the signal into approximation and detail coefficients for a wavelet basis set and the Hilbert spectra sifts through oscillatory modes of the signal to filter out intrinsic mode functions. We define statistical meta-tags as statistical moments, zero-crossings, location and number of the peaks and magnitude of peak values. These definitions capture salient characteristics of sensor stream like phase, amplitude, power, bandwidth, noise-level, periodicity, self-similarity etc.

With specific case studies in defense and security applications, we show our proposed framework can unearth and hypothesize anomalies in crime patterns, separate different types of random non-stationary noise in communication signals using the Fourier and Hilbert spectral descriptors, understand self-similarity patterns in the data and act as a new informative query-able data description layer between an interpreter/ modeler/investigator/decision maker and the raw data streams.

7666-26, Session 5

A new framework of multistage parametric inference and its applications in communication and control systems

X. Chen, Southern Univ. (United States)

In this paper, we propose a new framework of multistage parametric inference with wide applications in communications and controls. Within the new framework, we have developed specific multistage parametric estimation and hypothesis testing procedures which are rigorous and unprecedentedly efficient as compared to existing methods. In sharp contrast to classical sequential analysis methods which are dominantly of asymptotic nature, our procedures are of finite-time properties and thus is more realistic and useful for communication and control problems. To illustrate, we have applied our multistage methods to the problem of estimating the bit error rate of communication systems. Also, we have employed the new methods for estimation and testing the failure rate of control systems with varying parameters.

7666-27, Session 5

First-responder tracking and visualization for command and control toolkit

R. Woodley, P. V. Petrov, R. Meisinger, 21st Century Systems, Inc. (United States)

In order for First Responder Command and Control personnel to visualize incidents at building locations, DHS sponsored a small business research program to develop a tool to visualize 3D building interiors and movement of First Responders. 21st Century Systems, Inc. in response to the DHS program, has developed a toolkit we call: Hierarchical Grid Referenced Normalized Display (HiGRND). HiGRND utilizes three components to provide a full spectrum of visualization tools to the First Responder. First, HiGRND visualizes the structure and other surrounding structures in 3D. Utilities in the 3D environment allow the user to switch between views (2D floor plans, 3D spatial, single floor, multiple floors, etc.) and manually edit fast changing environments. HiGRND is able to accept CAD drawings and 3D digital objects (i.e., shape files) and render these in the 3D space. Second, HiGRND has a First Responder tracker that uses the transponder signals from First Responders to locate them in the virtual space. Additionally, we use the movements of the First Responder to map the interior of structures. The First Responder's search patterns are used as the base for the mapping then applying machine intelligence we determine what is causing the movement (walls, doorways, stairs, etc.). Finally, HiGRND has a tool to turn 2D blueprints into 3D objects. The 3D extruder extracts walls, symbols, and text from scanned blueprints to create the 3D. HiGRND greatly increases the situational awareness of First Responders and will save lives by allowing them to make better, faster decisions in urban situations.

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7666-28, Session 5

A disaster evacuation planning tool (ADEPT)

J. T. Feeley, J. R. Lavoie, Rite-Solutions, Inc. (United States)

Hurricanes Katrina and Rita demonstrated the difficulty of moving people out of harms way during a crisis. Each of the storms highlighted a different problem. Katrina demonstrated the importance of recognizing how devastating a hurricane can be and the importance of rapid evacuation. This was the driver that pushed people to immediately evacuate as Hurricane Rita was moving in. However the very evacuation iyself resulted in massive traffic jams on Interstate 45 leaving people stranded for hours on the highway without access to essentials.

This paper will discuss an application that can optimize evacuation routes on a neighborhood by neighborhood basis. It will take into account the dynamic influences of rapidly flooding roads, downed power lines, burning buildings, traffic loading on each of the highways etc. Optimization here means moving the most people out of danger without creating further disruptions. It does not mean taking the most direct route to safety.

Our methodology was to create a flooding model for Boston as a function of a Category 3 storm and a gradient of storm surges from 2 feet to 12 feet in in 2 foot increments.

We will then employ modeling and simulation toos to display evacuation routes for various areas of Boston based on what routes remain open.

7666-29, Session 5

Bayesian-performance metrics and small-system integration in recent homeland security and defence applications

T. P. Jannson, A. A. Kostrzewski, E. Patton, R. D. Pradhan, M. Shih, K. Walter, G. Savant, R. Shie, Physical Optics Corp. (United States)

In this paper, Bayesian inference is applied for performance metrics definition of the broad variety of recent homeland security and defense systems, including both internal system performance and CONOPS. The medical analogy is used to define the PPV (Positive Productive Value), the basic Bayesian metrics parameter. Also, Small System Integration (SSI) is discussed in the context of recent homeland security and defense applications, including a highly multi-technologic approach, within the broad range of clutter (nexus) of electronic, optical, and other technologies.

7666-30, Session 5

A Bayesian-belief network of threat anticipation and terrorist motivations

G. O. Allgood, M. M. Olama Husseini, Oak Ridge National Lab. (United States); K. M. Davenport, Southwestern Univ. (United States)

Recent events highlight the need for tools to anticipate threats posed by terrorists. In order to anticipate threats, one must understand all aspects of threat elements such as physical and social aspects. To analyze such components, we developed a two-layer Bayesian belief network (BBN) model that takes into consideration the relative threat of an attack against a particular asset by a particular threat (physical layer) as well as the individual psychology and motivations that would induce a person to join a terrorist group and commit terrorist acts (social layer). After researching the many possible motivations to become a terrorist, the main factors are compiled and sorted into categories such as initial and personal indicators, exclusion factors and predictive behaviors. Assessing these threats requires combining information from disparate data sources such as analytic models, simulations, historical data, sensor networks,

and user judgments. BBN combines these disparate data in a coherent, analytically defensible, and understandable manner and it deals with various types of uncertainties. The developed BBN model considers the likelihood of an attack and the consequences if that attack were to occur so that mitigation efforts can be optimally employed. It is constructed using a network engineering process that treats the probability distributions of the BBN nodes within the broader context of the system development process as a whole and not in isolation. Simulation results are provided to demonstrate the method's viability.

7666-31, Session 5

Noncontact physiological sensing and fusion for detection of malintent

C. A. McPherson, A. K. Webb, The Charles Stark Draper Lab., Inc. (United States); D. J. Martin, MRAC (United States); S. M. Wendelken, J. D. Coleman, D. C. Reed, The Charles Stark Draper Lab., Inc. (United States)

Security at airports, seaports, major sporting events, and other similar venues present a challenge to the organizations responsible for protecting people and property from individuals with malintent. Due to the quantity of people passing through security checkpoints, it is often the role of security personnel with various skill levels to assess the potential for malintent in each individual by observing behaviors and detecting potentially harmful items in their possession within a very short time span.

Recent advances in remote sensing technology have provided the capacity to detect many behavioral and physiological signals remotely without the need to attach devices to the body. The application of such devices to security screening has the potential for aiding in the process by providing an unbiased assessment. This paper provides a brief discussion of some candidate applicable sensors and techniques for use in the identification of malintent through feature extraction, data fusion, and classification employing such sensors.

7666-32, Session 5

Detection of deception in structured interviews using sensors and algorithms

M. Cunha, The Charles Stark Draper Lab., Inc. (United States); A. Clarke, J. Martin, J. Beauregard, MRAC (United States); A. K. Webb, A. Hensley, N. Keshava, The Charles Stark Draper Lab., Inc. (United States); D. Martin, MRAC (United States)

Draper Laboratory and MRAC have recently completed a comprehensive study to quantitatively evaluate deception detection performance based upon different interviewing styles. Furthermore, the interviews have been performed while multiple physiological waveforms are collected from participants to determine how well automated algorithms can detect deception based upon changes in physiology. We report the results of a multi-factorial experiment with 80 human participants who were deceptive on specific topics during interviews conducted with one of two styles: a forcing style which relies on more coercive or confrontational techniques, or a fostering approach, which relies on open-ended interviewing and elements of a cognitive interview.

The interviews were performed in a state-of-the-art facility where multiple sensors simultaneously collect synchronized physiological measurements from the participant, including electrodermal response, relative blood pressure, respiration, pupil diameter, and ECG. Several features extracted from these waveforms during honest and deceptive intervals after every question were then submitted to a hypothesis test to evaluate their statistical significance. A univariate statistical detection algorithm then evaluated the ability to detect deception for different interview configurations. Algorithm performance was also correlated with the results of questionnaires completed by each participant to provide demographic background as well as assessments of the experiment.

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Our paper will explain the protocol and experimental design used for this study and will also describe the different psychological assessments collected from each participant. Our results will be in terms of statistical significances, effect sizes, and ROC curves and will specifically identify how promising features performed in different interview scenarios.

7666-33, Session 5

Sensing systems efficiency evaluation and comparison for homeland security and homeland defense

A. A. Pakhomov, Security&Defense Research LLC (United States)

Designers and consumers of various security, intelligence, surveillance and reconnaissance (ISR) systems as well as various unattended ground sensors pay most attention to their commonly used performing characteristics such as probability of a target detection and probability of a false alarm. These characteristics are used for systems comparison and evaluation. However, it is not enough for end-users of these systems as well as for their total/final effectiveness assessment. This article presents and discusses a system approach to an efficiency estimation of the security and ISR systems. Presented approach aims at final result of the system's function and use. It allows setting up reasonable technical and structural requirements for the security and ISR systems, makes trustworthy comparison and practical application planning of such systems. It also allows finding forward-looking, perspective ways of systems development. Presented results can be guidance to both designers and consumers.

7666-109, Session 5

A tactical RF communication network vulnerability assessment using Bayesian networks

P. Chan, M. Mansouri, H. Man, Stevens Institute of Technology (United States)

Tactical wireless RF network vulnerabilities continually being reported and critically studied recently. A comprehensive network vulnerability assessment approach has been an increasing challenge to research analysts. Researchers have proposed a variety of methods to build network trees with chains of exploits, and then perform vulnerability analysis of a given RF network. Recent approaches build attack trees by enumerating all potential attack paths, which are space consuming and result ineffective. This short paper presents an approach to use Bayesian network to model all potential attack paths in tactical RF wireless network. We will call such graph as RF networks "Bayesian vulnerabilities graph". It provides a more compact representation of attack paths than conventional methods. Bayesian inference methods can be used for probabilistic analysis. In particular, the focus will be on the algorithm for updating, and algorithm to compute an optimal subset of attack paths relative to our knowledge about attackers. Tactical RF wireless models were created and simulated on an example network using the DoD DISA provided OPNET JCSS simulation and modeling communication software. Test results demonstrate the effectiveness of approach. The research may help to develop a more systematic and automated approach for building attack graphs in tactical wireless RF networks. Bayesian network is designed in attack graph and model all potential attack steps in a given network. Each RF wireless network node represents a single security property violation mode; each RF link edge corresponds to exploit of one or more possible vulnerabilities and each network path represents a series of exploitations that can signify a potential attack within the RF wireless network.

7666-110, Session 5

Optical receiver for high-speed communication

P. A. Mitchell, V. Grib, PHOTONIS USA Inc. (United States)

For through-the-air optical communication applications, we present a high speed detector module with high bandwidth and large active area. The detector has achieved a rise time of 220 pS with a full-width-half-max of 420 pS. Data rates are expected to approach 2 GHz. The active area of the input window is 12 mm, giving a large collection surface for through-the-air applications. The detector module includes an integrated power supply having low power consumption.

In comparison with other detector technologies, this new detector exceeds the speed of conventional photomultiplier designs by 3 to 5 times. In comparison with microchannel plate detectors, the speed is comparable, but the throughput of the new detector is much higher - tens of microamperes of signal current can be obtained indefinately.

Optical communication applications can be served by two different designs. In the first case, the module utilizes gain based on ordinary secondary emission materials to achieve current gains of 1500. This design is suitable for applications at the limit of the detector's bandwidth where light power is relatively high. In another design, the secondary emission material was changed to diamond film which allows five times higher gain. While the current design uses an ordinary, blue sensitive input light conversion material, higher efficiency materials are in development for signals at longer wavelength.

7666-34, Session 6

Extreme health sensing: the challenges, technologies, and strategies for active health sustainment of military personnel during training and combat missions

M. J. Buller, U.S. Army Research Institute of Environmental Medicine (United States); O. Chadwicke Jenkins, Brown Univ. (United States); A. Welles, R. Hoyt, U.S. Army Research Institute of Environmental Medicine (United States)

Military personnel are often asked to accomplish rigorous missions in extremes of climate and terrestrial altitude. Personal protective clothing such as body armor or chemical biological suits and excessive equipment loads exacerbate these environmental stressors. Health, over even short mission durations can easily be compromised. Measuring and acting upon health information can provide a means to dynamically manage both health and mission goals. However, the measurement of health state in austere military environments is complex. (1) Sensors must be of minimal weight and size, consume little power, and provide negligible human factors impact. (2) Health states are often not directly measurable and must be estimated. (3) Sensor measurements are prone to noise, artifact, and failure. Given these constraints we examine current successful health sensing technologies, review maturing sensors that may provide key health state insight in the future, and discuss strategies that optimize health, mission goals, and doctrine.

7666-35, Session 6

TATRC advanced technologies in biosensors, biosurveillance, and disaster medicine

K. N. Montgomery, Telemedicine and Advanced Technology Research Ctr. (United States)

The goal of a real, practical, useful, and fully operational biosurveillance system for the United States has existed for some time. While many groups both internal and across government agencies have sought to

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produce such a system, attaining this goal has remained challenging.The needs for such a system are self-evident and significant- ranging from early detection and prevention of infectious disease, early detection of bioterrorism, general public health, environmental protection, and other influences, all of which have impact on millions of lives and economic impact in the billions of dollars annually. This presentation will focus on the projects involving biosurveillance that are under the oversight of TATRC to discuss these projects and technologies and develop methods for information sharing and true integration and fusion of the data, expertise, knowledge, core strengths and capabilities of all the groups internal and external to this portfolio. Through strong integration and collaboration, the combination of efforts is synergistic, and together may form the basis for a nucleus around which other projects and efforts in other organizations may be integrated. The ultimate vision is to develop the nucleus of an integrated, practical, operational and usable domestic and worldwide biosurveillance capability that is reliable, predictive, practical and widely employed.

7666-36, Session 6

Intelesense: global integrated monitoring

K. N. Montgomery, Intelesense Technologies (United States)

Never before in the history of mankind has our ability to acquire data about our planet and its inhabitants been so prolific. Data from in-situ sensors deployed worldwide, human-generated data (field reports, surveys, land use patterns, etc), and satellite imagery and other remote sensing data have produced an enormous amount of information totaling in the hundreds of gigabytes per day. This data, coupled with the broad ubiquity of the Internet has led to an unprecedented wealth of information available at every desktop. Intelesense Technologies was founded to provide worldwide integrated monitoring of the environment and its' inhabitants, to understand their interrelationships and improve our ability to protect the planet and its people. A global network of wireless sensor devices transmit their data to a grid-based computing server where they are integrated with hundreds of thousands of other data sources to help to better understand their interrelationships. This data, along with all data known from other sources in NASA, USGS, Google, and others are provided within a worldwide GIS browser (Inteleview) to provide interactive exploration of the world and its data. Current projects range from protecting some of the most beautiful and biodiverse places on our planet, to tracking emerging infectious diseases, to helping children from around the world to connect and interact with each other and better understand their environment and themselves.

7666-37, Session 6

The emerging role of global situational awareness 2.0 resources in disaster response

C. W. Taylor, Univ. of South Alabama (United States)

Global public health organizations are called upon to respond to emerging infectious disease events such as H1N1. One of the key components to effective public health engagement is situational awareness. The historic approach has been a very linear, top down, data for the sake of data driven structure, which often fails to collect the right data for non linear events or recognize fragile interdependencies from which data must also be acquired in order to create an effective public health response. The emergence of global situational awareness 2.0 solutions hold great promise that the right awareness can be acquired and shared across a broad spectrum of highly similar social networks of public health responders and other providers. It is now possible to link situational awareness, bio-surveillance, patient centric health records, real time medical response and decision support through global collaboration hubs that can optimize the ability to access knowledge about an event and to promote effective response.

7666-39, Session 7

Stress response biomarkers for noninvasive health sensing in humans and animals

Š. O. Southern, Gaia Medical Institute (United States)

Global biosurveillance and public healthcare need practical diagnostic tools for mass use in the field, and crosscutting biosensors for integrated monitoring of human, animal and environmental health. We have developed a new molecular technology called Stress Response Profiling (SRP) for integrated health sensing in people and animals. SRP uses a large panel of proteomic biomarkers to measure systemic cellular stress as a surrogate for physiological status. The SRP measurement serves as a molecular vital sign indicating a disease or exposure to stressors. SRP biomarkers monitor the activation of multiple stress response pathways to enable sensing of diverse health threats in multiple species. The combined biomarker panel provides a general health screen for a rapid triage of health threats. The profile of individual biomarkers classifies specific medical conditions. The major difference between SRP and other diagnostics is that the same biomarker panel is applicable to a wide spectrum of health threats including diagnostic 'blind spots' such as uncharacterized pathogens, emerging disease, novel toxins or effects of complex psychobiological stressors associated with disasters or warfighting .SRP biomarkers can be rapidly measured in noninvasive biological samples using low-cost, easy-to-use immunoassays. Current projects include general health screening in wild animals using a skin SRP test, and monitoring specific disease risk and response to treatment using saliva SRP tests for AIDS, PTSD, TBI and operational stress in warfighters.

7666-41, Session 7

Salivary protein profiles for rapid detection of diabetes and its complications

S. R. Nagalla, DiabetOmics (United States)

The twin epidemics of obesity and diabetes threaten to overwhelm healthcare systems in the U.S. and worldwide, with almost 29 million Americans currently having frank diabetes (predominantly type-2; T2DM) and an additional 68 million with prediabetes. A major challenge in dealing with the burden of diabetes is our inability to easily and conveniently detect diabetes and prediabetes in at-risk populations due to the lack of a non-invasive, point-of-care test. There is increasing evidence that periodontal disease and diabetes are related, and this connection is supported by our discovery of salivary biomarkers of diabetes. We have recently characterized the whole salivary proteome from controls and T2DM patients by multi-dimensional liquid chromatography-tandem mass spectrometry (2D-LC-MS/MS) to identify differentially abundant protein biomarkers. Characterization of the salivary proteome identified a total of 487 unique proteins. Approximately 33% of these have not been previously reported in human saliva. Of these, 65 demonstrated a greater than 2-fold difference in abundance between control and type-2 diabetes samples. Selected biomarkers are optimized to a prototype lateral-flow test device to produce a non-invasive, cost-effective, robust diagnostic with significantly improved accuracy, deliverability, and acceptability. In addition to a potential direct impact on diabetes detection and monitoring, the introduction of salivary biomarkers for diabetes will greatly expand the scope of salivary diagnostics.

7666-42, Session 7

A new biomarker test for monitoring depression risk and response to therapy

M. M. Rasenick, Univ. of Illinois at Chicago (United States) and PAX Neuroscience, Inc. (United States)

Clinical response to antidepressant therapy is usually delayed by a

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month or more subsequent to the initiation of therapy. At this point in time, no biochemical parameter has been developed that can identify treatment response. Preclinical studies in our laboratory have revealed that Gsalpha, a protein linked to several neurotransmitter receptors, is more active when outside of cholesterol-rich membrane domains known as lipid rafts. These studies also reveal that chronic treatment with any of the most commonly prescribed classes of antidepressants cause Gsalpha to be released from lipid rafts. A postmortem study has revealed that Gsalpha is more likely to be in the lipid raft fractions in brain samples culled from suicide cases with documented depression relative to samples from non-depressed control brains. We suggest that in human blood cells, the extent of lipid raft localization of Gsalpha is indicative of both depression and response to antidepressant therapy. More importantly, it is anticipated that these values will offer an early indication , in less than 5 days, of antidepressant response, allowing clinical decisions to be made much earlier in the course of therapy than is now possible. Early identification of the right antidepressant therapy is essential to decrease the risk of depression-related suicide and PTSD.

7666-43, Session 7

Hepcidin: an emerging biomarker for iron disorders, inflammatory diseases, and infections

M. Westerman, Intrinsic LifeSciences (United States)

Disorders of iron metabolism are among the most common human diseases. The peptide hormone hepcidin, a Type II acute phase reactant expressed in liver, has emerged as the master regulator of iron homeostasis. Dysregulation of hepcidin is the principal or contributing factor in most systemic iron disorders and in anemia of inflammation (anemia of chronic disease). Hepcidin is a small hormone essential for maintenance of healthy blood iron levels. Hepcidin regulates dietary iron absorption and transport from body iron stores to plasma. Abnormally high serum hepcidin levels commonly observed in chronic and acute inflammatory conditions and in bacterial infections, cause a debilitating anemia by limiting plasma iron available to make hemoglobin and blood. At the other extreme, low serum hepcidin levels cause toxic accumulation of iron in tissues with consequent organ failure, particularly liver and heart. Intrinsic LifeSciences (ILS) has developed and validated the world's first immunoassay for serum hepcidin using patent-pending technologies and established the normal ranges in adult males and females. Hepcidin has excellent characteristics as a biomarker including a known mechanism of action, large dynamic range, good stability, and rapid response to iron stores, inflammatory stimuli, and infection. Clinical studies show that serum hepcidin is not measurable in iron deficient/anemic patients and highly elevated in inflammatory conditions and infections. Hepcidin is easily measured in blood, urine, and saliva. ILS is automating the hepcidin immunoassay and developing low-cost, rapid result, lateral-flow field devices for hepcidin, a multi-purpose biomarker with potential to detect threats to force health and effectiveness.

7666-44, Session 8

Environmental, health, and safety effects of engineered nanomaterials: challenges and research needs

H. Fairbrother, The Johns Hopkins Univ. (United States)

The number of technologies and consumer products that incorporate engineered nanomaterials (ENMs) has grown rapidly with corresponding increases in their annual production rates. Inevitably, some of these synthetic materials will enter the environment either from incidental release during manufacture and transport or following consumer use and disposal. Consequently, intense scientific research is now being directed towards understanding the environmental, health and safety (EHS) risks posed by ENMs. I will highlight some of the key research challenges and needs in this area, including (i) developing structure-

property relationships that will enable physicochemical properties of ENMs to be correlated with environmentally relevant behavior (e.g. colloidal properties, toxicity), (ii) determining likely exposure routes and release rates of ENMs from consumer products, (iii) developing analytical techniques capable of detecting ENMs in the environment, (iv) designing models that use experimental data as inputs to accurately predict the fate and effects of ENMs in different ecosystems.

7666-45, Session 8

Quantum dots in life sciences: applications, benefits, and safety

J. B. Delehanty, C. E. Bradburne, K. L. Boeneman, K. Susumu, B. C. Mei, U.S. Naval Research Lab. (United States); J. B. Blanco-Canosa, P. Dawson, The Scripps Research Institute (United States); H. Mattoussi, A. L. Huston, I. L. Medintz, U.S. Naval Research Lab. (United States)

Luminescent semiconductor quantum dots (QDs) possess several unique optical and spectroscopic properties including high quantum yields, broad absorption spectra coupled to narrow symmetric, size-tunable emissions allowing large achievable Stokes shifts, and exceptional resistance to photo- and chemical degradation. These properties make QDs unique enabling materials for the development of the next generation of highly efficient biosensors for health security applications, particularly within the context of living and fixed cells. Paramount in this developmental process is addressing the biocompatibility of the QD materials. We are developing robust and facile delivery schemes for the selective intracellular delivery of QD-based nanoassemblies. These schemes are based upon the self-assembly and subsequent cellular uptake of QD-peptide and QD-polymer bioconjugates. Cellular delivery experiments utilizing both delivery schemes will be presented. The advantages and disadvantages of each approach will be discussed, including the intracellular fate and stability of the QD-nanoassemblies.

7666-46, Session 8

Engineered nanomaterials for biomedical applications

Z. P. Aguilar, Ocean Nanotech, LLC (United States)

Engineered nanomaterials such as quantum dots (QD), metal nanoparticles, magnetic nanoparticles, are a new class of materials with unique properties including 3-50 nm diameter, signal brightness, high photobleaching resistance, high magnetic and electric properties, and simultaneous excitation of multiple fluorescent colors. Magnetic nanoparticles are used in magnetic resonance imaging and targeted drug delivery. Several unique advantages of QDs include large molar extinction coefficients that increase QD brightness under photon-limited conditions. These unique properties permit detection at the single nanoparticle level, along with reliable quantification of binding and transport phenomena. The cross section of some QDs is more than 60 times larger than that of organic dye resulting in brightness that can be one or two orders of magnitude higher improving detection limit. QD are used in a broad range of applications including single molecule biophysics, biomolecular profiling, optical barcoding, in vivo and in vitro imaging, targeted drug delivery. We will describe biomedical applications of magnetic nanocrystals and semiconductor nanomaterials, and discuss applications of engineered nanomaterials in molecular imaging and in vitro diagnostics.

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7666-47, Session 9

Epidemiological monitoring for emerging infectious diseases

M. J. Greene, SAIC (United States)

SAIC has created a self-organizing ontology that allows us to organize and filter external data by relating email exchanges through their references into "reference-connected sets". These sets of messages can be generated dynamically and constructed in real-time to identify subject categories (e.g. disease outbreaks) as they evolve. This allows the filtering of less important information into sets of messages that uniquely identify events so the user is not overwhelmed with irrelevant information. This paper describes the approach as it is applied to ProMED-mail, an Internet-based system dedicated to rapid global dissemination of information on infectious diseases. This official program of the International Society of Infectious Diseases has the largest reporting base of any health organization and can be used as a model for a bio-threat surveillance system that takes advantage of decentralized, Internet-based social networks. The presenter will demonstrate how the technique was used in an analysis of the evolution of pandemic influenza messages. The presenter will also discuss the benefits of expanding the approach through new science and technology solutions to increase global health security. Examples are: user-friendly graphic interfaces; automated extraction and formatting of data; expert systems for epidemiologic analysis; powerful algorithms for data and information fusion; interconnection with other networks (public health agencies, hospitals, animal/zoonotic disease surveillance); standard forms through an internet.

7666-48, Session 9

Naval vessels as sentinel sites for influenza surveillance

C. Myers, Naval Health Research Ctr. (United States)

Over 500 throat swab samples and related clinical data were collected from patients with acute respiratory disease (ARD) onboard deployed naval ships in the course of investigative respiratory pathogen surveillance from 2002 through 2009. Swabs were collected by onboard medical personnel, with sampling concentrated during times of high ARD rates. Ships were provided with liquid nitrogen containers for stable sample storage, and samples were mailed on dry ice to a reference lab for testing when ships were in port. Samples were initially tested by strain-specific real-time PCR using in-house accredited (homebrew) methods, with verification by traditional culture and serological hemagglutination inhibition (HAI) methods. Cultured isolates were further characterized by sequencing the hemagglutinin gene using commercial dye-terminator methods. Many apparent outbreaks occurred after foreign port stops, and analysis of isolated strains associated with these events generally revealed seasonally dominant influenza strains circulating in the region of the port. Epidemic strains from both hemispheres were identified for all flu seasons sampled in those hemispheres. Emergent strains were often identified by shipboard collection before they were by more traditional sentinel sites in the US, despite the much smaller sample number and minimal sampling effort. We characterize the isolated strains by analysis of the hemagglutinin gene sequence, associate identified strains with ports of origin, and compare the breadth of capture to land-based surveillance sites. Shipboard surveillance is extremely efficient, and efforts to optimize global surveillance of epidemic diseases should consider mobile elements of the transportation infrastructure, including military ships, airlines, and cruise ships.

7666-49, Session 9

Unanticipated impact of robustly designed, high-density resequencing micro-arrays for multiplex pathogen detection and identification

C. Tibbetts, M. Lorence, K. O. Schafer, Tessarae LLC (United States); D. Metzgar, C. Myers, Naval Health Research Ctr. (United States)

The TessArray® RPM-Flu resequencing pathogen microarray simultaneously detects and identifies thirty categories of viral and bacterial pathogens causing influenza or flu-like respiratory illness. Analytical and Clinical sensitivity of RPM-Flu is comparable RT-PCR tests, but RPM-Flu offers greater specificity through reports as multiple target pathogen gene sequences for each detected pathogen. RPM-Flu was designed in 2005 as concerns surrounded fatal human infections by virulent strains of A/H5N1 avian influenza. The RPM-Flu differentiates all Type A influenza viruses as subtype combinations of the known 16 hemagglutinin and 9 neuraminidase genes. The novel A/H1N1 swine-origin influenza virus strain (SOIV) emerged in Spring 2009 and it was immediately determined that the unmodified RPM-Flu assay effectively detects and differentiates SOIV from seasonal A/H1N1 and A/H3N2 strains.

7666-50, Session 9

Analysis of dust samples from the Middle East using high-density resequencing micro-array "RPM-TEI"

B. Lin, T. A. Leski, M. J. Gregory, A. P. Malanoski, J. P. Smith, Z. Wang, D. A. Stenger, U.S. Naval Research Lab. (United States)

In a previous study, we designed and validated a comprehensive resequencing microarray "Tropical and Emerging Infections (RPM-TEI v.1.0 chip)" for identifying and discriminating between tropical diseases and other potential biothreat agents, their near-neighbor species, and/or potential confounders which provides coverage of 72 microorganisms and 10 toxin genes. In collaboration with US navy reservists, RPM-TEI v.1.0 was used to characterize the microbes present in dust and air filters collected from Middle East. US personnel deployed to the Middle East as well as the local population are subjected to high levels of airborne desert dust containing a significant fraction of particles in the inhalable size range. The dust is capable of carrying a range of toxic chemicals and diverse microbial organisms associated with their surfaces. Clinical syndromes associated with exposure to the desert dust that were not directly attributable to physical action of sand have been reported but not much is known of their possible infectious origin. In order to understand the health effects of the airborne dust, this study investigated the composition of the microbial communities associated with dust samples of surface sand or airborne dust (air filter) from 19 different sites in Middle East. Previous studies using length heterogeneity PCR (LH-PCR) has shown that these samples harbor a variety of fungal and bacterial organisms. The sequences detected using RPM-TEI microarray indicated the presence of several microorganisms including a class of rapidly growing Mycobacterium, Bacillus, Brucella, Clostridium and Coxiella burnetti. Many of those microbes are associated with infections or respiratory illness and some of them (Bacillus, Coxiella) are known for their resistance to drying and ability to be spread over long distances. The presence of these infectious agents in the inhalable desert dust may pose a health hazard warranting further investigation to determine their impact on human health. Better understanding of microorganisms present in environmental samples is important to address questions related to human health in the Middle East, North Africa and other arid regions which is critical for Force Health Protection of the Naval Warfighter.

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7666-51, Session 9

Low-cost, easy-to-use infectious disease diagnostics for global health settings

B. H. Weigl, R. B. Peck, PATH Diagnostics Group (United States)

Pathogens, whether naturally or intentionally disseminated, don't stop at our borders. A bioattack or a pandemic can rapidly turn our healthcare system into a low resource setting. The PATH Diagnostics Group primarily develops infectious disease point-of-care assays specifically for use in low resource settings (LRS).

In this talk we will discuss similarities and differences between assays designed for LRS and for biodefense, and give examples of assays under development that can have applications for low resource and disaster medicine as well as biodefense in first responder settings. We will present our work on rapid immunoassays as well as a new generation of instrument-free molecular assays.

7666-52, Session 9

Development of low-cost field-deployable real-time PCR instruments

W. M. Nelson, A. M. de Vazeille, D. M. Almassian, J. Yu, S. Diepold, Tetracore, Inc. (United States)

Tetracore has independently developed a series of Real-Time PCR platforms, with low cost high quality optics, for use in field deployable operations, including:

1. A stand-alone 16 channel, three color/channel (currently FAM, CY5, and Pulsar 670), battery operated instrument with a standard USB 2.0 interface and optional laptop operation. It currently supports 7 hours of continuous operation of all four channels. Additional batteries can easily be added to increase operation time with minimal impact on the footprint of the instrument. This instrument can simultaneously perform 48 assays or 32 assays with internal controls (IC).

2. A stand-alone auto sampling single channel RT-PCR instrument designed for autonomous operation with environmental samples. The instrument has three color detection, simple sample clean up, and a proprietary RT-PCR mastermix that is highly resistant to inhibition.

These two machines are at the heart of this talk, but a major component is the dried real-time PCR and Isothermal reagents. The past 12 months we have worked with TwistDx real-time isothermal amplification reagents, primarily with assays for B. anthracis but also with two other BW agents. These instruments have also been tested with Tetracore commercial RT-PCR assays for Agro-Terorism.

7666-53, Session 9

Development of a microfluidic system for measuring CD4 cell count or HIV-1 viral load

U. Demirci, Harvard Medical School (United States)

HIV-1/AIDS has inflicted a tremendous economic and health burden worldwide, especially on the people in developing countries. With ongoing international efforts for expanding access to antiretroviral treatment (ART) in these resource-limited settings, there is an urgent need for monitoring CD4 cell count and HIV-1 viral load to assist with clinical decisions. However, current assays targeting CD4 cell count or HIV-1 viral load are costly and require basic infrastructure, which is not practical for resource-limited settings. We have proven the proof-of-principle of a microfluidic-based imaging and counting system aiming at CD4 cell count or HIV-1 viral load. For CD4 cell count, we have achieved an overall performance of 83.5 ±2.4% compared to standard flow cytometry. In addition, we have successfully captured and imaged HIV-1 viral particles using this system, paving the way of measuring HIV-1 viral load in unprocessed whole blood from AIDS patients. This simple, rapid and inexpensive system holds a great promise in curbing the HIV-1 pandemic.

7666-54, Session 9

Rapid, portable test systems: from miniaturized optical test systems to stable reference fluorescence materials

K. Faulstich, Embedded System Engineering GmbH (Germany)

Human genome identification, SNP detection, infectious disease testing, drugs of abuse testing and homeland security are among the most important diagnostic applications of field based tests. The term field based test used here is synonymous with the term decentralized testing, which also includes tests at the physician's office, first responders and at the Point-of-Care (POC). In this paper we show examples of highly sensitive, miniaturized and portable optical test systems working directly from crude samples to fully interpreted results in minutes. The accuracy and robustness of the readers in the field is validated by a self test performed using built-in stable reference materials. These materials show an extremely broad usable wavelength range and can be used as excitation, emission, life time and polarization standards. They were demonstrated to be exceptionally stable to extremely high light exposure (18MegaWatt per second) for a prolonged time period (900 minutes). Their usefulness can be extended to the calibration of laboratory-based optical spectrometers.

7666-55, Session 9

Method-adaptable fluorescence standards as flexible calibration tools for the standardization of fluorescence-based measurements

U. Resch-Genger, Bundesanstalt für Materialforschung und -prüfung (Germany)

Despite the increasing use of fluorescence techniques in the life and material sciences, the comparability of photoluminescence data across instruments is still limited due to general difficulties to consider instrument-specific spectral and intensity distortions of measured signals.To improve the reliability of fluorescence data and provide the basis for the accreditation of fluorescence techniques, simple and evaluated instrument characterization and performance validation tools are required as well as fluorescence intensity standards, thereby also meeting the increasing desire for quantification from measurements of fluorescence intensities. Additionally, to facilitate the choice of suitable fluorescence standards, application-specific requirements on different types of standards are needed including recommendable characterization procedures. This encouraged us to develop standards for different fluorescence parameters and fluorescence techniques for use under routine measurement conditions in different formates and measurement geometries. Special emphasis is dedicated to easy-to-operate liquid and solid fluorescence standards for the determination and control of the spectral responsivity of the emission channel, the wavelength accuracy, the spectral resolution, and the homogeneity of illumination for fluorescence instruments ranging from spectrofluorometers to fluorescence sensors and confocal laser scanning fluorescence microscopes.These standards can be also applied as day-to-day intensity standards to control the long-term instrument performance. As a first step towards a toolbox of standards, we developed strategies for multifunctional calibration tools exploiting application-specific combinations of different standards and optical components with defined absorption, scattering, and reflection properties. Here, we will present design concepts and examples for mono- and multifunctional fluorescence standards that provide traceability to radiometric units.

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7666-56, Session 9

Handheld flow cytometer for monitoring bacteria in water

P. Kiesel, M. Beck, N. M. Johnson, Palo Alto Research Center, Inc. (United States)

Water-quality monitoring is an essential priority for global health. It is estimated that worldwide more than 5000 people die daily from drinking contaminated water. With microorganisms a primary cause for the occurrence of infectious diseases, the concentrations of harmful bacterial cells should be routinely monitored to maintain microbiological quality control of drinking water. Because of the difficulty and cost of directly measuring all microbial pathogens in water samples, organisms like E.coli, Giardia and cryptosporiduim that indicate the presence of sewage and fecal contamination have been targeted for measurement. Bacterial quantitation is currently performed by labs that primarily use plate-culture assay techniques which can take up to 24 hours to produce test result. In order to achieve more timely assessment of water quality, we have developed and tested a hand-held, opto-fluidic-chip-based flow cytometer that promises to meet the requirements for point-of-need microbiological testing of water. The enabling technique is termed "spatially modulated fluorescence detection" and delivers high signal-to-noise discrimination without precision optics. Relative movement between analyte and a predefined patterned environment generates a time-dependent signal, and correlating the detected signal with the known pattern achieves high discrimination of the particle signal from background noise. The detection technique has been extensive evaluated and benchmarked against a commercial flow cytometer with measurements of absolute CD4+ and percentage CD4 counts in human blood, which are required for screening, initiation of treatment, and monitoring of HIV-infected patients. We have also assembled a first-generation, compact, handheld, single-parameter instrument based on the spatial modulation technique. The performance of this prototype provides a clear existence proof that a multi-parameter, high-performance, compact instrument for bacterial monitoring in water is fully realizable.

7666-58, Session 9

Real-time monitoring of processed water using a laser and UV-LED-induced fluorescence detection system

A. V. Sharikova, D. K. Killinger, Univ. of South Florida (United States)

We have developed a laser-induced fluorescence (LIF) system to detect and continuously observe in real time the levels of colored dissolved organic matter (CDOM) or Dissolved Organic Compounds (DOCs) in water from various sources, such as tap water and Reverse Osmosis water. At the same time, we have studied deep-UV LEDs as alternative light sources for our system, which would make the apparatus cheaper and more compact. Our portable LIF system had two interchangeable microchip Nd:YAG lasers, operating at 266 nm and 355 nm, as UV sources, and fluorescence was measured over the range of 240-680 nm. The fluorescence was collected at 90º to the laser beam. We have also studied deep-UV LEDs emitting at 265 nm and 320 nm as alternative sources of fluorescence excitation. The average laser power was approximately 30 times that of the LED. Fluorescence spectra from sea water, tap water, and reverse osmosis water for both excitation sources were also measured, and similar spectra were observed. Differences in the signal intensity due to the difference in the laser and LED excitation intensity were consistent with theory.

7666-59, Session 10

Behavioral analysis of loosely coupled systems

N. F. Sandell, G. V. Cybenko, Dartmouth College (United States)

Techniques for dynamic behavioral analysis and modeling have recently become an increasingly researched topic. In essence, they aim to understand the mechanics of a set of variables over time, allowing for prediction of future data, anomaly or change detection, or estimation of a latent variable. Much of this research has focused on the sequential analysis of individual tracks of data - for example, in multi-target tracking (MTT). In recent years, massive amounts of behavioral and usage data have become available due to the proliferation of online services and their large users bases. The data from these applications can not be said to be monolithically generated - there are many processes and activities occurring simultaneously. However, it also cannot be said that this data consists of a set of independently running processes, as there are often strong correlations among subsets of the variables. Therefore we have a potentially large set of loosely coupled entities that can be modeled neither as a single, large process, or a large set of individual processes. ``Static" applications, e.g. rating predictors for recommender systems, have greatly exploited entity to entity correlations through processes such as collaborative filtering. In this paper, we present a probabilistic model for loosely coupled and correlated dynamic data sets and techniques for making inference about the model. Experimental results are presented using data gathered from instrumented wireless access points around a college campus.

7666-60, Session 10

Requirements for sensors and command and control technologies for an integrated person-borne IED countermeasure architecture

N. J. Lombardo, C. K. Knudson, Pacific Northwest National Lab. (United States)

Developing an integrated person-borne IED countermeasure to protect unstructured crowds at public venues is the goal of the Standoff Technology Integration and Demonstration Program (STIDP), a collaboration of the U.S. Department of Homeland Security and Joint IED Defeat Organization (http://stidp.labworks.org). The architecture being developed includes countermeasure systems deployed as a layered defense and enabling technologies for operating the countermeasures as an integrated system. Early distinguishing of potentially higher-risk individuals is crucial. Sensors must be able to detect explosives threat signatures with high accuracy in varying environmental conditions, from a variety of approaches, and with dense crowds and limited dwell time. Command and control technologies are needed to automate sensor operation, reduce manpower requirements, improve situational awareness, and automate/facilitate operator decisions.

STIDP is developing technical and operational requirements for standoff and remotely operated sensors and is working with agencies to implement these requirements in their R&D programs. STIDP also is developing requirements for a software platform to rapidly integrate and control various sensors; acquire, analyze, and record their data; and present the data in an operationally relevant manner. Requirements also are being developed for spatial analysis, tracking and assessing threats with available screening resources, and data fusion for operator decision-making.

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7666-61, Session 10

Toward ubiquitous and adaptable infrastructures for distributed system protection and management

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

Many existing national and international infrastructures-from power to education to security to defense-are bureaucratic, clumsy, and based on fixed locations, links, and rules, same as their management facilities. They are poorly adjustable to new tasks, being also easy targets for terrorist attacks. Additional protective measures over them, like NIPP, pursuing similar principles, may not help much. A new ideology and technology are offered for the creation of intelligent distributed management and protection infrastructures which, in the form of integral spatial creatures, can freely migrate in distributed physical and virtual environments. Self-recovering, stealthy, and operating in different dimensions than friendly or hostile forces, they can effectively analyze, protect, or destroy other infrastructures. The technology installs universal control modules into important points (internet hosts, laptops, smart sensors, mobile robots or mobile phones) of distributed environments or other systems to be impacted. These, communicating, collectively interpret high-level self-evolving mission scenarios, which, in parallel virus-like mode, navigate distributed worlds spatially matching them, bringing needed operations and control, and setting distributed behavioral logic. Details of Distributed Scenario Language (DSL), the core of the approach, will be revealed, along with peculiarities of its software or hardware implementation, and numerous practical programming examples of parallel distributed solutions, including penetration into other systems with their topology analysis, spatial pattern matching between distributed graphs, and discovery and eradicating malicious intrusions and their infrastructures. Distributed dynamic control of power grids and use of collective robotics will be demonstrated in DSL too. References: NIPP, 2009; www.amazon.com sapaty in books.

7666-62, Session 10

Homeland defense application of the Army Soft Target Exploitation and Fusion (STEF) System

R. T. Antony, SAIC (United States); J. A. Karakowski, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

A fusion system that accommodates both extracted text-based information along with more conventional sensor-derived input has been developed and was demonstrated in a terrorist attack scenario as part of the Empire Challenge (EC) 09 Exercise. Although the fusion system was originally produced to support Army military analysts, the system design is based on foundational fusion principles, making the approach directly applicable to homeland defense, law enforcement, and other applications.

Several novel fusion technologies and applications were demonstrated in EC09. One is a novel approach to location normalization that accommodated both fuzzy semantic expressions such as behind Library A, across the street from the market place, as well as traditional spatial representations. Other applications, based on a set of 8 fundamental fusion forms, provide a framework to fuse information of interest in the homeland defense area. The fusion forms demonstrated capabilities which were not possible using traditional fusion technologies.

A formal test of the fusion system was performed during the EC09 exercise. The system demonstrated that it was able to (1) automatically form tracks, (2) help analysts visualize behavior of individuals over time, (3) link key individuals based on both explicit message-based information as well as discovered (fusion-derived) relationships, and (4) suggest possible individuals of interest based on their association to High Value Individuals (HVI) and user-defined key locations.

7666-63, Session 10

Port information exchange of response services (PIERS)

E. Chaum, Naval Undersea Warfare Ctr. (United States)

No abstract available

7666-65, Session 11

Continuous tracking and data association across cameras with disjoint fields-of-view

B. C. Matei, H. S. Sawhney, S. Samarasekera, J. Word, T. E. Germano, S. Wu, Sarnoff Corp. (United States)

We describe a new algorithm for performing continuous tracking of objects viewed by cameras with disjoint fields of view. Our main contributions in this paper are: (i) We detect moving objects in the image space using motion flow, and characterize each image region with several features measuring the 2D shape and appearance of targets, which are robust to changes in the viewpoint. From training data, we learn, individually for each type of feature, two-class classifiers that measure the likelihoods that two image regions are the same or not; (ii) We map the target tracklets extracted within each camera with a standard layer-tracker into a global reference coordinate system using the known extrinsic and intrinsic parameters of the cameras. We employ road networks and learnt traffic patterns to enforce kinematic constraints between the tracklets and rapidly prune-out impossible tracklet-to-tracklet pairings; (iii) The appearance constraints provided by the classifiers, together with the kinematic constraints provided by the road networks, and the learnt traffic patterns are employed within Multi Hypothesis Tracking (MHT) algorithm to join the tracklets from separate cameras into longer tracks. We illustrate our tracking algorithm on real data acquired from aerial cameras, and show excellent results with continuous tracking under very challenging conditions such as occlusions, significant spatial and temporal gaps between cameras.

7666-66, Session 11

Novel wavelength diversity techniques for high-speed atmospheric turbulence compensation

S. Sullivan, W. W. Arrasmith, Florida Institute of Technology (United States)

The defense, intelligence, and homeland security communities are driving a need for software dominant, real-time or near-real time atmospheric turbulence compensated imagery. The development of parallel processing capabilities are finding application in diverse areas including image processing, target tracking, pattern recognition, and image fusion to name a few. A novel approach to the computationally intensive case of software dominant optical and near infrared imaging through atmospheric turbulence is addressed in this paper. Previously, the somewhat conventional wavelength diversity method has been used to compensate for atmospheric turbulence with great success. We apply a new correlation based approach to the wavelength diversity methodology using a parallel processing architecture enabling high speed atmospheric turbulence compensation. Methods for optical imaging through atmospheric turbulence are discussed, simulation results are presented and computational and performance assessments are provided.

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7666-67, Session 11

Flat phased-array optical aperture at 1.3-1.5 microns

S. J. Papadakis, M. C. Gross, G. F. Ricciardi, I. N. Bankman, J. S. Peri, J. A. Krill, The Johns Hopkins Univ. (United States)

Electronic steering of lasers analogous to the steering of phased-array microwave antennas would allow precise laser steering within microseconds; replacing slow, cumbersome mechanical gimbals. We describe a design concept for a flat or conformal thin plate laser phased-array aperture. The aperture consists of a substrate supporting a grid of single-mode optical waveguides fabricated from a linear electro-optic material. The waveguides are coupled to a single laser source or detector. An arrangement of electrodes around the perimeter of the grid provides for two-dimensional beam steering and atmospheric turbulence correction by controlling the phase of the light entering the grid. At the intersections of the grid, small scatterers result in nearly isotropic radiation. Thus, the device is a good analogy to phased-array microwave antennas. A uniform grid with a minimum waveguide spacing imposed by the requirement of negligible inter-waveguide coupling would result in an undersampled aperture that exhibits many grating lobes. To sidestep this difficulty we apply spatial randomization to the emitter positions to decorrelate the grating lobes so as to obtain a viable aperture. The aperture will be a square ranging from 3 cm to 10 cm on a side, and will be capable of steering the main beam up to 45 degrees from the substrate normal. Applications include free-space communications and LIDAR. Initial estimates indicate that in communications applications the device could communicate directly with satellites and in LIDAR applications is fast and accurate enough for high-speed tracking of bullets. An approach for fabrication is outlined.

7666-68, Session 11

MWIR room temperature photodetector based on laser-doped silicon carbide

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MWIR photon detector in the mid-infrared wavelength (3 - 6 um) range is developed using crystalline silicon carbide substrates. SiC, which is a wideband gap semiconductor, is laser-doped to create a dopant energy level corresponding to a quantum of energy for the required operating wavelength of the detector. The photons of the objects in the field of view excite the electrons of the detector, leading to changes in the refractive index. This change in the optical property of the detector can be measured remotely with a laser beam, such as a He-Ne laser beam of wavelength 632.8 nm, which makes it a wireless detector. While many IR detectors require cryogenic cooling (77 K) to suppress thermal generation-recombination processes in order to operate with good detectivity, the SiC-based detector can operate at room temperature with excellent performance. An n-type 4H- SiC substrate has been doped with Ga by a laser doping technique to create a detector element for the MWIR wavelength of 4.21 um corresponding to the photon energy 0.30 eV. The dopant energy level is confirmed by optical absorption measurements. The change in the refractive index is studied as a function of absorbed irradiance on the detector. Other dopants can be incorporated into the 4H-SiC substrate to produce MWIR room temperature detectors for different wavelengths in the MWIR range.

7666-69, Session 11

Hybrid laser Doppler-active imaging surveillance system for detection of approaching small craft in open sea and harbor environments

D. M. Shemwell, Stellar Photonics, LLC (United States); S. E. Moody, Orca Photonic Systems, Inc. (United States) and Stellar Photonics, LLC (United States)

A new sensor system architecture combines Doppler velocity detection and active laser imaging to detect and then classify approaching small targets in a complex, cluttered marine environment. The intended applications of this system are for detection and classification of uncooperative small craft that may be threats to ships at sea, or to high value infrastructure in harbor. The use of velocity as a metric allows us to separate very small approaching targets from indigenous traffic and from sea clutter. A slaved active gated imaging subsystem allows for detailed identification of potential threats, once they have been filtered from the environment based on their approach velocity. Tracking of velocity offers a powerful tool for discriminating friend from foe in the intensely cluttered sea environment. Persistent approaching velocity is an unavoidable behavior for any target that intends to close the distance for hostile purposes. Our surveillance strategy is based on a sector scan approach, in which we scan a circular perimeter around the facility being protected, while measuring the velocity distribution of all objects within a given frame. Typical operating range is 100 to 1000m, depending on the environment. Scan times for 360 degrees are estimated to be of order 20 seconds. Our paper will show quantitative modeling of system performance for such a system, beginning from a level of coherent laser transmitter performance, operating in the eyesafe wavelength region, that we believe to be achievable within the framework of recent Er:YAG laser technology.

7666-70, Session 12

A multispectral automatic target recognition application for maritime surveillance, search, and rescue

J. Schoonmaker, Advanced Coherent Technologies LLC (United States); S. Reed, SeeByte Ltd. (United Kingdom); Y. Podobna, Advanced Coherent Technologies LLC (United States); J. Wood, F. Chataigner, SeeByte Ltd. (United Kingdom)

Due to increased security concerns, the commitment to monitor and maintain security in the maritime environment is increasingly a priority. A country's coast is the most vulnerable area for the incursion of illegal immigrants, terrorists and contraband. This work illustrates the ability of a low-cost, light-weight, multi-spectral, multi-channel imaging system to handle the environment and see under difficult marine conditions. The system and its implemented detecting and tracking technologies should be organic to the maritime homeland security community for search and rescue, fisheries, defense, and law enforcement. It is tailored for airborne and ship based platforms to detect, track and monitor suspected objects (such as semi-submerged targets like marine mammals, vessels in distress, and drug smugglers). In this system, automated detection and tracking technology is used to detect, classify and localize potential threats or objects of interest within the imagery provided by the multi-spectral system. These algorithms process the sensor data in real-time, thereby providing immediate feedback when features of interest have been detected. A supervised detection system based on Haar features and Cascade Classifiers is presented and results are provided on real data. The system is shown to be extendable and re-usable for a variety of different applications.

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7666-71, Session 12

Sirica low-cost high-performance IR detector for security camera

O. Nesher, Sirica Corp. (Israel)

The advantages of passive thermal IR imaging for security camera are well known from military use. Operation in total darkness, its effectiveness in motion detection and the fact that its location is unknown make it best option for early warning systems. Passive IR cameras are slowly penetrating into the civilian security camera market. Yet volume is low due to its high price. Most of the night vision camera solutions today are based on NIR sensitive CMOS/CCD sensors combined with illuminations, where these cameras are typically limited to few ten meters of men detection. Thermal cameras provide the optimal solution for outdoor perimeter security application requiring long detection range with over 1,000 meter detection rang. For these applications Sirica offer the novel low cost LWIR IR photonic detector operating at room temperature with non-vacuum package. As published previously, the basic concept of the detector is based on continuous LWIR to VNIR up-conversion layer, optically coupled to high resolution CMOS sensor. Using small pixel standard CMOS opens up new methods to reduce noise and improve the image quality of the IR detector. In this paper we describe the architecture and the unique features of Sirica novel LWIR detector for use in the security applications. Recent results of the prototype will be also presented

7666-72, Session 12

Wireless sensor network emergence, enhancement, and their deployment for various applications: an interactive study

N. Tiwari, Medicap Institute of Technology and Management (India)

Flexible and multi-adaptive platforms are always being appreciated by the people. In the field of Information Technology the Wireless Vision Network [WisVisNet] is one of the fastest growing segments. Due to their flexibility of networks and easy enhancement in the field of businesses, educational establishments and households; this becomes an integral form of life. The IEEE defines the IEEE 802.11 standard for the wireless network. Wireless traffic using a network card set to monitor RFMON mode. This paper deals with a continuous, interactive and integrative research effort in the field of wireless sensor network. The work described in this paper is our experience in building a complete system using Wireless Sensor Networks for a Vision Sensing application. This practical experience has been valuable, because it has taught us that some of the simplified assumption made about the Hardware Platform in much current research does not hold well in practice. The lessons we learned have greatly impacted some of the design choices we have to make in building any wireless surveillance system. The information is obtained in the form of video Information/Snapshot in our case; it has to be reported to a remote base station within an acceptable latency. In this paper various issue related to design and implementation of Wireless Vision Network is discussed.

7666-73, Session 12

Advances in IR thermal imaging for border defense

D. P. Forrai, J. W. Devitt, P. H. Smith, B. J. Rogers, L-3 Communications Cincinnati Electronics (United States)

Border Defense remains an urgent priority in the coming years. In order to meet DHS goals for 24/7 border surveillance capability, long range state of the art infrared imagers are needed to cover large areas economically. The long range gives both greater detection range, and therefore more

response time, as well as a reduced number of units to cover the same area thus reducing infrastructure cost. L-3 Communications Cincinnati Electronics is a premier supplier of long-range infrared imagers and has a portfolio of solutions with unmatched detection ranges. The sensitivity and resolution of these instruments offer a wide range of applications spaces including both Northern and Southern borders. As part of an integrated systems level solution, potentially including technology to control the environment such as atmospheric turbulence corrections, these imagers can enable high confidence border security.

7666-74, Session 12

Improved optical security system based on Vander Lugt correlator and fuzzy control iterative algorithm

J. Hu, K. Wu, X. Wu, Dalian Univ. of Technology (China); Y. Bai, Changchun Institute of Optics, Fine Mechanics and Physics (China)

An optical security system based on Vander Lugt correlator and fuzzy control iterative algorithm is proposed. This system can be used for personal verification or identification at banks, custom houses, and so on. Two phase masks are placed at the input plane and the Fourier plane of a Vander Lugt correlator, respectively, and a correlation image of the two phase masks is obtained at the output plane of the correlator. Firstly, an original image is selected for each user, and the phase mask in the Fourier plane is generated. Then the phase mask in the input plane is computed by phase retrieval algorithms and dispatched to each user. In the verification process, if the user provides the correct phase mask, the correlator will reconstruct the original image, otherwise won't. The quality of the recovered image is very important, because it is used to judge whether the phase mask from the user is a genuine one. Previous researches used algorithms like the G-S algorithm to generate the phase mask, and always led to a poor reconstruct quality. In this paper, we present an iterative algorithm based on fuzzy control theory to improve the quality of the recovered image.

This paper firstly analyzed the performance of the G-S and the Sleek Revise algorithm, and summarized the advantages and disadvantages of them. Then an iterative algorithm based on the fuzzy control theory is used to take advantages of them. This algorithm intelligently control the iterative process of the program, actively chose the G-S or the Sleek Revise algorithm by fuzzily determining which approach is better for the current iterative cycle. Computer simulation results show that when the iterative algorithm based on fuzzy control theory is used, the obtained image at the output plane is better than that of G-S and Sleek Revise algorithm. This paper gives an improved optical security system with better reconstruction quality.

7666-108, Session 12

Characterization of an InGaN-based photo-emissive device

J. W. Glesener, L-3 Electro-Optical Systems (United States); A. M. Dabiran, SVT Associates, Inc. (United States); J. P. Estrera, L-3 Electro-Optical Systems (United States)

InGaN alloys have been exploited in many nitride optoelectronic devices. InGaN semiconductor alloys potentially have a detection range from the UV out to 1. m. In an image intensifier package, this would enable a light weight, high resolution detector with gain.

This work reports on the application of InGaN alloy fluctuations in a packaged vacuum electronic device utilizing an InGaN photocathode as the detector element. Exploitation of the particular InGaN properties of alloy fluctuations in a transmission mode photocathode is advantages because of the ability to use a wider bandgap spectral material to achieve a longer wavelength spectral response. This property has further positive consequences for photocathodes. One, it lessens the strain at

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the sapphire-AlN-InGaN interface because a lower In percentage InGaN film is required to achieve the spectral response of a higher In alloy composition. Secondly, the wider bandgap InGaN matrix material will have a lower amount of thermionic emission while still retaining the longer wavelength photoresponse provided by the alloy fluctuations. Thirdly, an InGaN alloy with visible response holds the promise in that it can be grown directly on a sapphire window as opposed to the compression bonding of GaAs originally reported by Antypas and Edgecumbe.

7666-75, Session 13

Solar-powered wireless sensing systems for border security

H. Zhang, M. Fallahi, S. Pau, R. A. Norwood, N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States)

A secure border necessitates the development of new technology for remote sensing and surveillance. We investigate and develop wireless sensor network systems consisting of spatially distributed sensor nodes that can monitor various environmental parameters including temperature, humidity, motion, vibration, etc. The sensors, nodes and transceivers are of low-power consumption and powered by solar energy so that the systems can work over long time periods with minimal human intervention and maintenance. This paper presents the technology development, wireless sensor integration, power management, and communication architecture, as well as demonstration of environmental monitoring.

7666-76, Session 13

Passive tracking of targets using electric-field sensors

S. T. Beardsmore-Rust, P. B. Stiffell, H. Prance, R. J. Prance, P. Watson, Univ. of Sussex (United Kingdom)

We have reported previously on the use of a novel Electric Potential Sensor, developed and patented at the University of Sussex, for remote monitoring of life signs [1] and through-wall sensing of movement and proximity [2]. In this paper we present the data obtained using a sparse (3-element) array of sensors to image a volume of space for target movements. This is achieved by passive monitoring of the disturbances which result from the movement of a dielectric object through the ambient electric field. Numerical computation is used to simulate the expected sensor responses for a given pattern of movement and comparison with these simulations allows the position and velocity of the target to be tracked. With this 3-element array, it is possible to track the movement of a single subject, for example an intruder, or the lone occupant of a room. However, we show that with the addition of just a few extra sensors, it is possible to resolve the ambiguities caused by multiple targets.

The advantage of this approach over competing radar technologies, for through-wall surveillance [3,4] and tracking [5], is that the method is passive. It requires no excitation field or probe signal and relies instead on the ambient static electric field which exists between the ionosphere and the surface of the Earth. It therefore only works well if the array is not obstructed by conducting materials, in common with the other technologies. However, the passive nature of the technique provides a low power system which is potentially undetectable.

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7666-77, Session 13

Smart sensing surveillance system

C. C. Hsu, Trident Systems Inc. (United States); K. Chu, U.S. Dept. of Homeland Security (United States); J. O'Looney, M. I. Blake, Trident Systems Inc. (United States)

Unattended ground sensors (UGS) network have been widely used in remote battlefield and other tactical applications including border surveillance, special forces operations, perimeter and building protection, target acquisition, situational awareness, and force protection. In this paper, a highly-distributed, fault-tolerant, and energy-efficient Semantic Mesh of Intelligence Sensors (SMIS) System is presented to efficiently provide 24/7 and all weather security operation in a situation management environment. The SMIS system is composed of a number of distributed SMIS nodes to collect, process, and disseminate heterogeneous sensor data. Every SMIS node has passive sensors to provide rapid omni-directional detection. PTZ EO/IR cameras are integrated to selected nodes to track the objects and capture associated imagery. These nodes will provide applicable advanced on-board digital image processing capabilities to detect and track the specific objects. The imaging detection operations include unattended object detection, human feature and behavior detection, and configurable alert triggers, etc. In the SMIS system, all the nodes are connected with a robust, reconfigurable, LPI/LPD (Low Probability of Intercept/ Low Probability of Detect) wireless mesh network using UWB RF technology to provide an ad-hoc, secure mesh network and capability to relay network information, communicate and pass situational awareness messages. The SMIS utilizes a Service Oriented Architecture such that remote applications can interact with the SMIS network and use the specific presentation methods. The SMIS system is compliant with Open Geospatial Consortium - Sensor Web Enablement (OGC-SWE) standards.

7666-78, Session 13

Autonomous energy harvesting embedded sensors for border security applications

A. Hande, P. L. Shah, Texas MicroPower, Inc. (United States); J. N. Falasco, D. Weiner, Crane Aerospace and Electronics (United States)

Currently, both static fencing and passive barriers used for perimeter security are subject to damage from vandalism and therefore, extremely high maintenance costs. The use of seismic sensors to detect activity around the fence can be used to alert security personnel of potential threats. Wireless networks of seismic sensors have proven to be a valuable tool for providing security forces with intrusion alerts even in densely forested areas. The cost of replenishing the power source is one of the primary obstacles preventing the widespread use of wireless sensors for fence and passive barrier protection.

This paper focuses on making use of vibration energy due to fence movements to power the wireless sensors. A system comprising of Texas MicroPower's (TMP's) energy harvesting device integrated with Crane Wireless Monitoring Solutions's MicroObserver® sensor nodes is described. The energy harvesters are suitable for integration and for low cost, high volume production. TMP has an exclusive license to a patent on a recently developed piezoelectric composition with the highest ever reported energy density for bulk piezoelectric ceramics and is in the process of developing piezoelectric thin-film MEMS processes using this newly discovered composition. The harvesters are used for powering sensors in Crane's wireless hub and spoke type sensor network. Adaptive power management circuits that allow harvesting from multiple sources are employed. The MicroObserver® sensors will incorporate sophisticated seismic detection algorithms to optimize performance for sensors embedded in and along the fence. The measured data is used to determine the node location and detect untoward activity.

Primary Topical Area: Unattended Ground, Sea and Air Sensor and Tagging Systems and Technologies.

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7666-79, Session 13

Robust site security using smart seismic array technology and multisensor data fusion

D. R. Hellickson, Honeywell Aerospace (United States); P. Richards, Z. G. Reynolds, Quantum Technology Sciences, Inc. (United States)

Traditional site security systems are susceptible to high individual sensor nuisance alarm rates that reduce the overall system effectiveness. Visual assessment of intrusions can be intensive and manually difficult as cameras are slewed by the system to non intrusion areas or as operators respond to nuisance alarms. Very little system intrusion performance data is available other than discrete sensor alarm indications that provide no real value.

This paper discusses the system architecture, integration and display of a multi-sensor data fused system for wide area surveillance, local site intrusion detection and intrusion classification. The incorporation of a novel seismic array of smart sensors using FK Beamforming processing is discussed that greatly enhances the overall system detection and classification performance of the system. Recent test data describes the performance of the seismic array within several different installations and its ability to classify and track moving targets at significant standoff distances with exceptional immunity to background clutter and noise. Multi-sensor data fusion is applied across a suite of complimentary sensors eliminating almost all nuisance alarms while integrating within a geographical information system to feed a visual-fusion display of the area being secured. Real-time sensor detection and intrusion classification data is presented within a visual-fusion display providing greatly enhanced situational awareness, system performance information and real-time assessment of intrusions and situations of interest with limited security operator involvement. This approach scales from a small local perimeter to very large geographical area and can be used across multiple sites controlled at a single command and control station.

This paper maps to the Infrastructure Protection and Counter Terrorism Systems and Technologies focus area within Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense VIX (DS106)

7666-80, Session 13

Heightened performance for seismic beamforming at tactical scales

P. Richards, A. Pitarka, Z. G. Reynolds, A. Frey, Quantum Technology Sciences, Inc. (United States)

We have recently applied Intelligence, Surveillance, and Reconnaissance (ISR) concepts that produce real time situation displays from arrays of inexpensive seismic acoustic (SA) sensors buried in shallow holes in the ground. Significant technical results are available in the areas of beamforming, detection, and classification of operationally significant sources such as human footsteps, motor vehicles, and aircraft at long standoff distances. A new sensor provides excellent sensitivity and coherency that are readily exploited using well-established beamforming techniques. These techniques have been used for years for applications involving earthquakes and large explosions on a global scale. Only recently, however, has seismic beamforming technology been applied to local scales of interest to tactical commanders. Tactical sources often simultaneously excite different modes of seismic and acoustic propagation and classic delay-and-sum fixed beams have trouble accounting for variations in frequency and propagation speed. To handle these differences, geophysicists long ago devised an array processing technique known as Frequency Wavenumber (FK) beamforming. We apply FK beamforming to problems at tactical scales and use it to track human and vehicle signatures in a 2-D slowness space that reports direction of arrival of seismic and acoustic energy. This paper develops topics in array and algorithm design, and demonstrates system performance using simulated and actual data collected in the field.

7666-81, Session 13

Energy harvesting with low-power electronics

T. P. Jannson, T. C. Forrester, K. Degrood, E. Gans, K. S. Lee, K. Nguyen, K. Walter, Physical Optics Corp. (United States)

In this paper, a novel concept of energy harvesting, applicable to both wired and wireless self-powered electronic devices is discussed. Types of energy harvesting include: solar, thermal, IR, mechanical, etc. Overall power budget and control circuitry are discussed, including maximizing Mean Time between (Battery) Replacement/Recharge value. It is shown that in the case of low-power wireless electronics, the reasonable time of direct solar daily exposure is sufficient to satisfy the overall system power consumption

7666-82, Session 13

Multiple-input multiple-output (MIMO) analog-to-feature converter chipsets for sub-wavelength acoustic source localization and bearing estimation

S. Chakrabartty, Michigan State Univ. (United States)

Localization of acoustic sources using miniature microphone arrays poses a significant challenge due to fundamental limitations imposed by the physics of sound propagation. With sub-wavelength distances between the microphones, resolving acute localization cues become difficult due to precision artifacts. In this work, we present a miniature, high-density microphone array sensor that uses real-time spatio-temporal cues to estimate the bearing of an acoustic target. At the core of the proposed sensor is a patented Multiple-input Multiple-output Analog-to-digital conversion technology which overcomes the limitation of precision artifacts by integrating signal-measurement (analog-to-digital conversion) with statistical learning (bearing estimation). The paper presents the hardware implementation of the acoustic source localizer which integrates the MIMO-ADC chip-sets with array of differential microphones. Measured results from fabricated prototypes demonstrate a detection range of 0 degrees to 90 degrees with a bearing resolution less than 2 degrees. The power dissipation of the MIMO-ADC chip-set for this task was measured to be less than 75 microwatts making it ideal for portable, battery powered sniper and gunshot detection applications.

7666-83, Session 13

Low-frequency signals detection and identification as a key point of software for surveillance and security applications

A. A. Pakhomov, Security&Defense Research LLC (United States)

Various passive as well as active surveillance and security systems try to detect and identify very low frequency signals. Diversity of such real time working systems is very broad. Those are seismic, acoustic, hydroacoustic, IR, ultrasound, etc. systems. Detected target spectrum is also broad: from human motion on the ground surface and under water to low-noise submarines. In real application corresponding signals have poor signal-to-noise ratio, unstable shape and amplitude, short duration, and even missing parts of the signal. This paper describes test records of some raw seismic, IR and acoustic signals with proper characteristics. We investigate those signals specifics and possible approach to target oriented reliable signal processing that allows drastically increasing detection range and reducing false alarm rate. We also report on the preliminary field-testing that was implemented with modified two-channel seismic sensors and IR detectors.

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7666-84, Session 13

Validation of a BOTDR-based system for the detection of smuggling tunnels

I. Elkayam, A. Klar, R. Linker, A. M. Marshall, Technion-Israel Institute of Technology (Israel)

Cross-border smuggling tunnels enable unmonitored movement of people, drugs and weapons and pose a very serious threat to homeland security. Recently, Klar and Linker (2009) [SPIE paper no. 7316-2] presented an analytical study of the feasibility of a Brillouin Optical Time Domain Reflectometry (BOTDR) based system for the detection of small sized smuggling tunnels. The current study extends this work by validating the analytical models against strain measurements of real soil obtained from small scale experiments in a geotechnical centrifuge. The centrifuge allows the study of real-scale problems involving soil non-linearity by creating an environment of elevated acceleration within a scaled-down model, thus obtaining the correct ground stress profile necessary to achieve similitude between the model and prototype. The soil strains were obtained using an image analysis method that tracked the displacement of discrete patches of soil through a sequence of digital images taken of the soil around the tunnel during the centrifuge test.

7666-85, Session 14

Weapon identification across varying acoustic conditions using an exemplar embedding approach

S. M. Khan, A. Divakaran, Sarnoff Corp. (United States)

In this paper we present a first study to classify firearm type across different recording conditions using an exemplar embedding approach. We demonstrate that a small number of exemplars can span the space of gunshot audio signatures and this optimal set can be obtained using a wrapper function. Our dataset includes 20 different gun types captured in a number of different conditions. We show that we can reduce our exemplar space to only 4 uniquely different gunshots without significantly limiting the ability of our embedding approach to discriminate different gunshots in the training and testing sets. By projecting a given gunshot to the subspace spanned by the exemplar set a distance measure/feature vector is obtained that enables comparisons across different recording conditions. This approach also has the potential for analyzing and describing acoustic environment conditions to assist in situational awareness. Finally we investigate the use of a hierarchy of gunshot classifications, which assists in improving finer level classification by pruning out gunshot labeling that is inconsistent with its higher level type.

Our experimental results show that gunshot classification across different recording conditions can be performed at a reasonable degree of certainty (60-72%) at a finer level (gunshot to weapon model) and at a high degree of certainty (95-100%) at a higher degree of abstraction (gunshot to `handgun' or `rifle'). We also investigate the use of simulated recording conditions and artificial noise to quantitatively evaluate the performance of our approach.

7666-86, Session 14

Results of field testing with the FightSight infrared-based projectile tracking and weapon fire characterization technology

S. R. Snarski, A. Menozzi, T. Sherrill, C. Volpe, M. Wille, Applied Research Associates, Inc. (United States)

This paper describes experimental results from recent live-fire data collects designed to demonstrate the capability of a prototype system for projectile detection and tracking. This system, which is being developed under the FightSight program, uses a high-speed thermal camera and sophisticated image processing algorithms to detect and track projectiles. The FightSight operational vision is an automated situational-intelligence technology to detect, track, and graphically map large-scale firefights and individual shooting events into command and control (C2) systems in real time (shot location/direction, weapon ID, movements/trends). Gaining information on enemy fire trajectory allows educated inferences on the enemy's intent, disposition, and strength.

Our prototype projectile detection and tracking system has been tested at the Joint Readiness Training Center (Ft Polk, LA) during live-fire convoy and mortar registration exercises (Jun 2009). The prototype system was also tested during staged MOUT firefight events at Aberdeen Test Center (Aberdeen, MD) under the Hostile Fire Defeat (HFD), Army Technology Objective midterm experiment (August 2009). Fusion with acoustic and EO sensors was also introduced for the HFD experiment to provide 3D localization and real time display of firing events. Results are presented that demonstrate highly effective and accurate detection and localization of weapon fire (5.56mm, 7.62mm, .50cal, 60/81/120mm mortars, 40mm) in diverse and challenging environments (dust, heat, day/night, rain, arid open terrain, urban clutter).

FightSight's TRL 6 capabilities demonstrated under these live-fire data collects could support close combat scenarios. As development continues, FightSight will be able to feed C2 systems with a symbolic mapping of enemy actions.

7666-87, Session 14

Minimizing the search space in sniper localization using sensor configuration

T. Damarla, U.S. Army Research Lab. (United States)

A novel algorithm for localizing the sniper location will be presented that uses only the time difference of arrival (TDOA) of muzzle blast and shock wave at disperate single microphone sensors. Use of only TDOAs eliminate need for sensor synchronization and makes the algorithm useful for man wearable system.

Several single microphone sensors make TDOA measurments and share them with other sensors along with their location information. The algorithm computes the sniper location. A mathematical formulation of the problem is given and an approach to solve the problem is proposed. In order to reduce the search space for possible sniper location, upper and lower bounds on the distances are estimated based on the sensor position configuration.

The algorithm results on data collected in a field will be presented. The results show that the algorithm is able to localize the sniper position within 10 meters.

Further research areas will be presented and improvements to the algorithm will be discussed.

7666-88, Session 14

Sniper detection using infrared camera: technical possibilities and limitations

M. Kastek, R. Dulski, P. Trzaskawka, G. Bieszczad, H. Madura, Military Univ. of Technology (Poland)

The paper discusses technical possibilities to build an effective system for sniper detection systems using infrared cameras. Description of phenomena to make possible sniper activities detection in infrared spectra as well as analysis of physical limitations was done. Cooled and uncooled detectors were considered. Requirements for detection, recognition and identification of sniper were defined and analyzed. Three phases of sniper activities were taken into consideration: before, during and after the shot. On the basis of experimental data the parameters defining the target (sniper and muzzle flash) were determined, which are essential in assessing the capability of infrared camera to detect sniper activity. The simulation of detection ranges was done for chosen scenarios of sniper detection task. The system configuration was

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proposed, capable of fulfilling the requirements. The discussion of the results of analysis and simulations was finally presented.

7666-89, Session 14

Rifle integrated muzzle reference sensor for accuracy optimization

S. Rajic, P. G. C. Datskos, W. R. Lawrence, Oak Ridge National Lab. (United States)

Traditionally the methods to increase firearms accuracy, particularly at distance, have concentrated on barrel isolation (free floating) and substantial barrel wall thickening to gain rigidity. This barrel stiffening technique did not completely eliminate oscillations but the amplitude of oscillation was dramatically reduced for a given input energy. This process, although highly successful, comes at a very high weight penalty. Obviously the goal would be to lighten the barrel (firearm), yet achieve even greater accuracy. Thus if ultra-light-weight barrels could be compensated for both their static and dynamic mechanical perturbations, the result would be very accurate yet significantly lighter weight weapons. We will discuss our development of a barrel reference sensor system that is designed to accomplish this ambitious goal. Our optical fiber based sensor monitors the barrel muzzle position and autonomously compensates for any induces perturbations. The reticle is electronically adjusted in position to compensate for the induced barrel deviation in real time.

7666-90, Session 15

Wide-area active collaborative tracking of waterborne vessels

A. Tamrakar, S. Jung, C. Broaddus, A. Divakaran, H. S. Sawhney, Sarnoff Corp. (United States)

We describe a real-time wide area surveillance system (WA-ACTV) for the automatic tracking of waterborne vessels using a network of PTZ cameras operating as a single connected system to provide persistent visibility of targets and seamless tracking between different cameras. The system optimizes the cost based assignment of cameras to targets using criteria such as target-value, pixels-on-target, target-visibility based on a geometric model and minimum camera switching. The system is able to provide seamless long range tracking of vessels owing to smooth target "hand-off" from one PTZ to another and, more importantly, owing to the vessel "fingerprints" that are acquired while tracking. Vessels are fingerprinted using a scale-invariant part-based representation constructed from a codebook of representative local patches which are themselves obtained by training on a large database of vessels. These fingerprints are used for reacquiring lost tracks when the vessel comes back into view in a different sensor thus allowing the system to extend the tracking range over the wide area of surveillance.

The system is thus capable of optimally managing the cameras to simultaneously track a large numbers of vessels over a large area. Currently, we have realized a small-scale version of the system described and demonstrated it in an inland waterway as well as a small section of a sea port. The system operates in real-time at a frame rate of 15 Hz and is easily scalable to hundreds of PTZ cameras. The fingerprint-based reacquisition of targets/tracks has been evaluated to have an accuracy of 91%.

7666-91, Session 15

Task-specific sensor settings for electro-optical systems in a marine environment

P. B. W. Schwering, S. P. van den Broek, R. A. Kemp, H. A. Lensen, TNO Defence, Security and Safety (Netherlands)

In current electro-optical sensor systems processing of imagery is seldom task-specific. Using task-specific settings of sensors, processing and fusion can improve the performance of electro-optical systems dramatically. This paper discusses the effect of dynamic sensor settings as function of specific tasks and environmental parameters and how these can play a role in the management of sensors in a naval application. In addition a series of experiments with different targets are presented to demonstrate the benefit of sensor management.

Keywords: Adaptive Sensor Management, Sensor Settings, Sensor Tasks, Panoramic Vision, IRST segment, Detection, Image Enhancement, Image Fusion, Image Stitching.

7666-92, Session 15

A demonstration of a low-cost approach to security at shipping facilities and ports

R. C. Huck, M. K. Al-Akkoumi, R. W. Herath, J. J. Sluss, Jr., S. Radhakrishnan, T. L. Landers, Univ. of Oklahoma (United States)

Government funding for the security at shipping facilities and ports is limited so there is a need for low cost scalable security systems. With over 20 million sea, truck, and rail containers entering the United States every year, these facilities pose a large risk to security. Securing these facilities and monitoring the variety of traffic that enter and leave is a major task. To accomplish this, the authors have developed and fielded a low cost fully distributed building block approach to port security at the inland Port of Catoosa in Oklahoma. Based on prior work accomplished in the design and fielding of an intelligent transportation system in the United States, functional building blocks, (e.g., Network, Camera, Sensor, Display, and Operator Console blocks) can be assembled, mixed and matched, and scaled to provide a comprehensive security system. The following functions are demonstrated and scaled through analysis and demonstration: Barge tracking, credential checking, container inventory, vehicle tracking, and situational awareness. The concept behind this research is "any operator on any console can control any device at any time."

7666-93, Session 15

Homeland security applications of video equipment located at fish ladders

C. S. Bendall, J. T. Barnett, D. Hakes, Engineering Special Programs Corp. (United States)

Video imaging equipment is a standard at most fish counting facilities, co-located with fish ladders or other fish choke points, utilized to identify, count and monitor indigenous fish species. The video is used as a real time enhancement to human counters, or to document fish passage for review either hours or days later. Fish counting facilities literally provide a window monitoring the real time health of many of America's important waterway systems. Real-time automated processing of the video could provide valuable warning of imminent natural or man-made environmental threats. Dual fish monitoring and homeland security usages for the video are not well documented. The paper summarizes the results of our investigation into potential dual use applications of fish counting video equipment, with application to homeland security, along with a review of image and signal processing techniques, which may improve the performance and efficacy of such systems.

7666-94, Session 15

A smart ROV solution for ship hull and harbor inspection

S. Reed, J. Wood, SeeByte, Inc. (United States)

Hull and harbor inspections currently involve unacceptable levels of

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human risk and monetary resources. Modern Remotely Operated Vehicles equipped with Smart ROV and sensor-processing solutions provide features and capabilities previously unavailable. Operations once carried out by divers can now be carried out more quickly, efficiently and safely by smart enabled, man portable ROVs.

Dynamic Positioning Control software provides ROV and pilot the capability to inspect complex environments. This application and the user interface allow the ROV to conduct complex maneuvers relative to the area being inspected and relieves the training requirements and work load for the pilot, allowing him to focus on his primary task of looking for possible threats (such as IEDs, Limpet Mines, signs of sabotage, etc).

Real-time sensor processing tools can be integrated into the smart ROV. Real-time ATR algorithms are used to search through the sensor data collected by the ROV and provide immediate feedback on threats. Sensor data may also be mosaic'd and imaging sensors can be optimized with real time 3D reconstruction techniques; providing the operator with real-time situational awareness of the coverage map and the hull or seafloor.

ROVs equipped with the right sensors and running the Smart ROV control system can inspect an harbor region, autonomously provide coverage information, identify possible threats and provide the level of control required to operate in confined environments. Legacy data is also used for change detection applications. These technologies have been tested extensively in real applications and are demonstrated here using real data and examples.

7666-95, Session 15

Defeating underwater improvised threats (DUIT)

J. T. Feeley, J. Burns, Rite-Solutions, Inc. (United States)

Rapid detection and classification of underwater explosive devices is critical to protecting innocent lives and maintaining the day to day flow of commerce. Rite Solution is a member of the UPSIDE team with Raytheon, General Dynamics Purvis, Farsounder and ASA. UPSIDE is a congressionaly funded port security soluition.

This paper will discuss merging lessons learned in UPSIDE and our own ASW experience with work being done by Dr Jimmie Oxley's group at the URI Center of Excellence in Explosives.

Dr Oxley's group is mapping the movement of precursor materials for WMDs and other explosives to develop strategies for dealing with this threat. The underwater domain has an additinal layer of complexity impacting the movment of these precursor materials. This is particularly true for nanosized particles.

We will discuss transitioning Rite View into a CONOPS solution using Narragansett Bay as the test bed. It will be designed to serve as a customizable solution that could be transferred to other ports and waterways.

7666-96, Session 15

Benthic microbial fuel cells: preliminary data from systems deployed in Boston Harbor

P. Girguis, Harvard Univ. (United States)

No abstract available

7666-97, Session 15

Rule-based expert system for maritime anomaly detection

J. Roy, Defence Research and Development Canada (Canada)

Maritime domain operators/analysts have a mandate to be aware of all that is happening within their areas of interest/responsibility. This

mandate derives from the needs to defend sovereignty, protect critical infrastructures, counter terrorism, detect illegal activities, etc., and it has become more challenging in the past decade, as commercial shipping turned into a potential threat. In particular, a huge portion of the data and information made available to the operators/analysts is mundane, from maritime platforms going about normal, legitimate activities, and it is very challenging for them to detect and identify the non-mundane. To achieve such anomaly detection, they must establish numerous relevant situational facts from a variety of sensor data streams. Unfortunately, many of the facts of interest just cannot be observed; the operators/analysts thus use their knowledge of the maritime domain and their reasoning faculties to infer these facts. As they are often overwhelmed by the large amount of data and information, automated reasoning tools could be used to support them by inferring the necessary facts, ultimately providing indications and warning on a small number of anomalous events worthy of their attention. Along this line of thought, this paper describes a proof-of-concept prototype of a rule-based expert system implementing automated rule-based reasoning in support of maritime anomaly detection. Knowledge acquisition from experts of the operational community, a taxonomy of maritime situation anomalies, the fundamental principles and components of a rule-based expert system, symbolic processing and forward chaining are discussed, along with practical implementation and performance details.

7666-98, Session 16

DHS counter-MANPADS program: scope and results

K. D. Wilson, U.S. Dept. of Homeland Security (United States)

This invited paper will discuss the scope of activities and evaluation program results of the US DHS multi-year Counter-MANPADS program. This program, mandated by the US Congress and managed by the DHS S&T Directorate, has evaluated the suitability and efficacy of active infrared laser countermeasure systems to protect commercial aircraft from shoulder launched missiles. A final report is scheduled for delivery to the US Congress before the end of calendar year 2009. DHS

7666-99, Session 16

Jeteye® Commercial Manpads System Flight Program: results and status

L. Nuzzo, M. R. Collette, BAE Systems (United States)

No abstract available

7666-100, Session 16

Northrop Grumman's Guardian™ Pod: program history and future opportunities

D. Denton, Northrop Grumman Electronic Systems (United States)

No abstract available

7666-101, Session 16

Countering Manpads: study of new concepts of applications

J. Audren, Sagem Défense Sécurité (France)

No abstract available

Conference 7666: Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense IX

SPIE
Defense,
Security + Sensing

7666-102, Session 16

The technology of explosives detection for transportation threats

E. C. Neiderman, U.S. Dept. of Homeland Security (United States)

No abstract available

7666-103, Session 16

Capacity utilization study for aviation security cargo inspection queuing system

G. O. Allgood, M. M. Olama Husseini, J. Lake, Oak Ridge National Lab. (United States); D. Brumback, Delta Cargo Facility (United States)

Beginning in 2010, the U.S. will require that all cargo loaded onto passenger aircraft be inspected. This will require more efficient processing of cargo and will have a significant impact on the inspection protocols and business practices of government agencies and the airlines.

In this paper, we conduct performance evaluation study for an aviation security cargo inspection queuing system for material flow and accountability. The queuing model employed in our study is based on discrete-event simulation and processes various types of cargo simultaneously. Onsite measurements are collected in an airport facility to validate the queuing model. The overall performance of the aviation security cargo inspection system is computed, analyzed, and optimized for the different system dynamics. Various performance measures are considered such as system capacity, residual capacity, throughput, capacity utilization, subscribed capacity utilization, resources capacity utilization, subscribed resources capacity utilization, and number of cargo pieces (or pallets) in the different queues. These metrics are performance indicators of the system's ability to service current needs and response capacity to additional requests. We studied and analyzed different scenarios by changing various model parameters such as number of pieces per pallet, number of TSA inspectors and ATS personnel, number of forklifts, number of explosives trace detection (ETD) and explosives detection system (EDS) inspection machines, inspection modality distribution, alarm rate, and cargo closeout time. The increased physical understanding resulting from execution of the queuing model utilizing these vetted performance measures should reduce the overall cost and shipping delays associated with new inspection requirements.

7666-104, Session 17

Multichannel millimeter-wave image registration and segmentation for concealed-object detection

D. Lee, S. Yeom, J. Son, S. Kim, Daegu Univ. (Korea, Republic of)

We address an image registration and segmentation method to detect concealed weapons by a passive millimeter wave (PMMW) system. The millimeter waves penetrate into specific materials such as plastic, paper, wood, clothing and hair, and the reflectivity on the metal and man-made objects is very high, therefore the concealed object can be easily detected by a PMMW imaging system. In this paper, 8mm multi-channel PMMW imaging system which operates at both 8mm and 3mm regimes with linear polarization. A matching process is preceded to register images obtained from different channels, and then, the concealed object region is segmented from the background of the body. The registration is performed by means of the geometric feature extraction and the matching processes. To segment the concealed object, the Linde-Buzo-Gray (LBG) vector quantization algorithm is adopted to utilize multi-channel information. In the experiment, the automated image registration

and segmentation are performed with various concealed objects including metal, and liquid and gel containers. The proposed method is shown to well register and segment the concealed object for automatic identification.

7666-106, Session 17

Detection of explosive by using the EURopean Illicit TRAfficking Countermeasures Kit (EURITRACK) inspection system

D. Sudac, M. Baricevic, J. Obhodas, K. Nad, Institut Ruder Boškovic (Croatia); C. Carasco, B. Perot, Commissariat à l'Énergie Atomique (France); V. Valkovic, A.C.T.d.o.o. (Croatia)

A tagged neutron inspection system has been developed inside the EURITRACK ''EURopean Illicit TRAfficking Countermeasures Kit'' and now Eritr@C ''European Riposte against Illicit tr@ffiCking'' project. Both project have been financed by European Union and partly by the participating organization. At the moment over 150 sea going cargo containers were investigate and adequate decision making algoritam are going to be developed. For the first time simulant of the RDX explosive was measured in a different environment and its gamma ray spectra were compared with the gamma ray spectra of a benign materials like paper, sugar and rise. ''Fingerprint'' of the simulant was found by measuring the C/O, N/C ratio as well as by making the triangle plot whose coordinates are made of the carbon and oxygen content and density. Density was found by measuring the intensity of the transmited tagged neutrons. In that way presence of the simulant was confirmed by using the two different methods. The possibility of using the triangle plot for detection of drugs like heroin, cocain and marihuana are also discused.

7666-107, Session 17

A distributed sensor system for detection of toxic and hazardous gases

A. K. Dutta, Banpil Photonics, Inc. (United States)

This paper presents a highly sensitive distributed sensor system to detect toxic gas like carbon monoxide (CO) and hazardous gas like hydrogen (H2). The sensor system is based on AlGaN/GaN heterostructures with floating gates as the catalytic adsorption surfaces for the target gases. Due to the presence of 2-dimensional electron gas (2-DEG) at the heterointerface, AlGaN/GaN based High Electron Mobility Transistor (HEMT) and Metal-Oxide-Semiconductor HEMT (MOS-HEMT) is highly sensitive to the changes in surface charge conditions. The individual sensor is made selective towards a specific target by the design of different gate structures. From the simulation results, it has been found that this type of high mobility field-effect devices can be applied to detect low concentrations (< 1 ppm) of gases with widely linear sensor characteristics.

AlGaN/GaN based wide bandgap devices have become very attractive for the detection of chemicals, gases, liquids or biomolecules. This paper presents a highly sensitive and selective device structures for the detection of two vital gaseous substances: CO and H2 using AlGaN/GaN HEMT and MOS-HEMT based floating gate devices. The detection of CO is used as the precursor for fire as well as to prevent CO gas poisoning. The low level (1 ppm) detection of CO has been reported using the Pt modified carbon nanotubes. The advantages of field-effect transistor (FET) based sensors are the amplification attained with transistor action, the larger linear range of detection, and the simple integration with the existing fabrication technology. AlGaN/GaN HEMT based FETs exhibit superior device/sensor performances due to enhanced material properties and the heterostructure junction compared to other FETs.

Conference 7667: Biometric Technology for Human Identification VII

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Biometric Technology for Human Identification VII

7667-01, Session 1

Sketch-to-photo matching: a feature-based approach

B. Klare, A. K. Jain, Michigan State Univ. (United States)

This paper presents a local feature-based method for matching facial sketch images to face photographs, which is the first known feature-based method for performing such matching. Starting with a training set of sketch to photo correspondences (i.e. a set of sketch and photo images of the same subjects), we demonstrate the ability to match sketches to photos: (1) directly using SIFT feature descriptors, (2) in a "common representation" that measures the similarity between a sketch and photo by their distance from the training set of sketch/photo pairs, and (3) by fusing the previous two methods. For both matching methods, the first step is to sample SIFT feature descriptors uniformly across all the sketch and photo images. In direct matching, we simply measure the distance of the SIFT descriptors between sketches and photos. In common representation matching, the distance between the descriptor vectors of the probe sketches and gallery photos at each local sample point is measured. This results in a vector of distances across the sketch or photo image to each member of the training basis. Further recognition improvements are shown by score level fusion of the two sketch matchers. Compared with published sketch to photo matching algorithms, experimental results demonstrate improved matching performances using the presented feature-based methods.

7667-02, Session 1

A novel thermal face recognition approach using face pattern words

Y. Zheng, Alcorn State Univ. (United States)

A reliable thermal face recognition system can enhance the national security applications such as prevention against terrorism, surveillance, monitoring and tracking, especially at nighttime. The system can be applied at airports, customs or high-alert facilities (e.g., nuclear power plant) for 24 hours a day. In this paper, we propose a novel face recognition approach utilizing thermal (long wave infrared) face images that can automatically identify a subject at both daytime and nighttime. With a properly acquired thermal image (as a query image) in monitoring zone, the following processes will be employed: normalization and denoising, face detection, face alignment, face masking, Gabor wavelet transform, face pattern words (FPWs) creation, face identification by similarity measure (Hamming distance). If eyeglasses are present on a subject's face, an eyeglasses mask will be extracted, and then masked with all comparing FPWs (no more transforms). A high identification rate (96.30%) has been achieved upon our preliminary face dataset from the proposed approach regardless operating time and glasses-wearing condition.

7667-03, Session 1

Superquadric representation of 3D faces: reducing time complexity of recognition

M. Mudigonda, G. C. Stockman, Michigan State Univ. (United States)

Human faces are smooth and symmetrical, making superquadrics a good choice for representation and normalization. We present a novel approach to parameterize 3D faces using the powerful superquadric model in combination with an eigen decomposition which represents the finer features of faces. The superquadric fit also provides axes of symmetry that yield a normalized face coordinates necessary for applying PCA. Results of fitting on the Computational Face Depth Map (CFDM) MSU data set show accurate representation for yaw, pitch, and roll with average rotations in the order of 10^{-3} about each axis.

Parametrization can be used to effectively partition the search space into smaller bins thus effectively reducing the search space complexity for matching and recognition. We show that it is possible to create about 20-40 clusters with as few as 30 shape parameters. The accuracy of the clustering algorithm, in some cases, is as high as 90%. We further evaluated the effectiveness of our clustering approach by running the Iterative Close Point (ICP) matching algorithm on all pairs of face scans in a cluster and show that we can achieve an average variance of about +/- 1.5mm which is the threshold for matching, thus validating the effectiveness of our approach.

7667-04, Session 1

Face recognition for standoff applications

C. I. Podilchuk, W. Hulbert, R. Flachsbart, L. Barinov, DSCI (United States)

A new face recognition algorithm has been proposed which is robust to variations in pose, expression, illumination and occlusions such as sunglasses. The algorithm is motivated by the Edit Distance used to determine the similarity between strings of one dimensional data such as DNA and text. The key to this approach is how to extend the concept of an Edit Distance on one-dimensional data to two-dimensional image data. The algorithm is based on mapping one image into another and using the characteristics of the mapping to determine a two-dimensional Pictorial-Edit Distance or P-Edit Distance. We show how the properties of the mapping are similar to insertion, deletion and substitution errors defined in an Edit Distance. This algorithm is particularly well suited for face recognition in uncontrolled environments such as stand-off and other surveillance applications. We will describe an entire system designed for face recognition at a distance including face detection, pose estimation, multi-sample fusion of video frames and identification. Here we describe how the algorithm is used for face recognition at a distance, present some initial results and describe future research directions.

7667-05, Session 1

Recognizing faces like humans

B. Kamgar-Parsi, U.S. Naval Research Lab. (United States)

No abstract available

7667-06, Session 2

On latent fingerprint enhancement

S. Yoon, J. Feng, A. K. Jain, Michigan State Univ. (United States)

Automatic feature extraction in latent fingerprints is a challenging problem due to poor quality of most latents, such as unclear ridge structures, overlapped lines and letters, and overlapped fingerprints. We have proposed a latent fingerprint enhancement algorithm which requires manually marked region of interest (ROI) and singular points. The core of the proposed enhancement algorithm is a novel orientation field estimation algorithm, which fits orientation field model to coarse orientation field estimated from skeleton outputted by a commercial fingerprint SDK. Experimental results on NIST SD27 latent fingerprint database indicate that by incorporating the proposed enhancement

algorithm, the matching accuracy of the commercial matcher was significantly improved.

7667-07, Session 2

Mobile, contactless, single-shot, fingerprint capture system

G. Abramovich, K. Harding, S. Manickam, J. Czechowski, V. Paruchuru, R. W. Tait, C. A. Nafis, GE Global Research (United States); A. Vemury, U.S. Dept. of Homeland Security (United States)

In some screening applications such as at field stations, disaster situations or similar conditions, it is desirable to have a contactless, rugged means to collect fingerprint information. The approach described in this paper enables acceleration of the capture process by eliminating an otherwise system and finger cleanup procedure, minimizes the chance of the spread of disease or contaminations, and uses an optical system able to provide rolled equivalent fingerprint information desirable for reliable 2D matching against existing databases. The approach described captures high-resolution fingerprints and 3D information simultaneously using a single camera without any moving parts to reduce cost and complexity of the information as well as system robustness. Data collection is expected to take less than 100 milliseconds, capturing all four-finger images simultaneously to avoid sequencing errors. This paper describes the various options considered for contactless fingerprint capture, and why the particular approach was investigated.

7667-08, Session 2

Tools for quality control of fingerprint databases

S. Swann, Federal Bureau of Investigation (United States); J. M. Libert, National Institute of Science and Technology (United States); M. A. Lepley, MITRE Corp. (United States)

Integrity of fingerprint data is essential to biometric and forensic applications. Accordingly, the FBI's Criminal Justice Information Services (CJIS) Division has sponsored development of software tools to facilitate quality control functions relative to maintaining its fingerprint data assets inherent to the Integrated Automated Fingerprint Identification System (IAFIS) and Next Generation Identification (NGI). This paper provides an introduction of two such tools. The first FBI-sponsored tool was developed by the National Institute of Standards and Technology (NIST) and examines and detects the spectral signature of the ridge-flow structure characteristic of friction ridge skin. The Spectral Image Validation/Verification (SIVV) utility differentiates fingerprints from non-fingerprints, including blank frames or segmentation failures erroneously included in data; provides a "first look" at image quality; and can identify anomalies in sample rates of scanned images. The SIVV utility might detect errors in individual 10-print fingerprints inaccurately segmented from the flat, multi-finger image acquired by one of the automated collection systems increasing in availability and usage. In such cases, the lost fingerprint can be recovered by re-segmentation from the now compressed multi-finger image record. The second FBI-sponsored tool, CropCoeff was developed by MITRE and thoroughly tested via NIST. CropCoeff enables cropping of the replacement single print directly from the compressed data file, thus avoiding decompression and recompression of images that might degrade fingerprint features necessary for matching.

7667-09, Session 3

Large-scale biometric systems

J. Fondeur, Sagem Défense Sécurité (France)

Biometric techniques play a unique role for identity management in that it is the only technology permitting to actually link a physical person with an "identity", whether it is an physical identity (like in a forensic system or to produce/use identity documents such as passport or drivers licenses) or a digital identity (for example for on line services). Hence biometric systems are also becoming increasingly larger, and several projects are being deployed or developed to handle populations of hundreds of millions, and up to a billion people.

This talk will describe the key challenges met when designing such systems as well as present the state of the art of the technology and how those challenges are addressed today. In particular, the impact of various factors (such as type of biometrics, quality of data, matching architecture,...) on biometric performance and system feasibility will be discussed and illustrated through concrete examples.

7667-10, Session 3

Visual cryptography for face privacy

A. A. Ross, A. Othman, West Virginia Univ. (United States)

We discuss the problem of preserving the privacy of a face image. In the proposed scheme, a private face image is dithered into two host face images such that it can be revealed only when both host images are simultaneously available; however, the individual host images do not reveal the identity of the original image. In order to accomplish this we appeal to the field of Visual Cryptography. Experimental results confirm the following: (a) the possibility of hiding a private face image in two public face images; (b) the successful matching of face images that are obtained after reconstruction by superimposing the host images; (c) the effect of various parameters on matching accuracy; and (d) the inability of the host (sheet) images to reveal the identity of the secret face image.

7667-11, Session 3

Cryptographically secure biometrics

A. Stoianov, Information and Privacy Commissioner/Ontario (Canada)

Biometric systems usually do not possess a cryptographic level of security: it has been deemed impossible to perform a biometric authentication in the encrypted domain because of the natural variability of biometric samples and of the cryptographic intolerance even to a single bite error. Encrypted biometric data need to be decrypted on authentication, which creates privacy and security risks. On the other hand, the known solutions called "Biometric Encryption (BE)" or "Fuzzy Extractors" can be cracked by various attacks, for example, by running offline a database of images against the stored helper data in order to obtain a false match. In this paper, we present a novel approach which combines Biometric Encryption with classical Blum-Goldwasser cryptosystem. In the "Client - Service Provider (SP)" or in the "Client - Database - SP" architecture it is possible to keep the biometric data encrypted on all the stages of the storage and authentication, so that SP never has an access to unencrypted biometric data. It is shown that this approach is suitable for two of the most popular BE schemes, Fuzzy Commitment and Quantized Index Modulation (QIM). The approach has clear practical advantages over "homomorphic encryption" biometric systems. The proposed solution can even be applied to one-to-many biometric systems.

7667-12, Session 3

Analytical template protection performance and maximum key size given a Gaussian-modeled biometric source

E. Kelkboom, J. Breebaart, I. Buhan, Koninklijke Philips Electronics N.V. (Netherlands); R. N. J. Veldhuis, Univ. Twente

(Netherlands)

Template protection techniques are used within biometric systems in order to protect the stored biometric template against privacy and security threats. A great portion of template protection techniques are based on extracting a key from or binding a key to a biometric sample. The achieved protection depends on the size of the key and its closeness to being random. In the literature it can be observed that there is a large variation on the reported key lengths at similar classification performance of the same template protection system, even when based on the same biometric modality and database. In this work we determine the analytical relationship between the system performance and the theoretical maximum key size given a biometric source modeled by parallel Gaussian channels. We also determine the effect of the parameters such as the source capacity, the number of enrolment and verification samples, and the operating point selection on the maximum key size. We show that a trade-off exists between the privacy protection of the biometric system and its convenience for its users.

7667-13, Session 3

A hierarchical fingerprint alignment method and its application to fuzzy vault

P. Li, X. Yang, Y. Zang, K. Cao, J. Tian, Institute of Automation (China)

Fuzzy vault is a practical and promising scheme, which can protect biometric templates and perform secure key management simultaneously. Aligning the query sample and the template sample in the encrypted domain remains a challenging task in the fingerprint-based fuzzy vault scheme. To some extent, all the existing fingerprint aligning methods in the encrypted domain have their own drawbacks, e.g., not enough alignment accuracy or information leakage because of publishing helper data. In this paper, a novel fingerprint aligning method is proposed, which integrates the fingerprint reference points and its neighboring region of interest(ROI) in a hierarchical manner. The concept of mutual information(MI) in the information theory is used to assess the coincidence extent of two fingerprints after being aligned. The novel alignment method is applied to fingerprint-based fuzzy vault implementation. Out of information leakage consideration, the orientation features of fingerprint minutiae are discarded and another distinguishing local feature, inter-minutiae ridge count, is used to replace the minutiae orientation in the implementation of fingerprint-based fuzzy vault. Experiment on FVC2002 DB2a is conducted to obtain the result of GAR=87%(FAR=0) and show the virtue of proposed alignment method and the promising performance of proposed fingerprint-based fuzzy vault implementation.

7667-14, Session 4

A central-limit theorem for a single-false match rate

Z. Dietz, Hamilton College (United States); M. E. Schuckers, St. Lawrence Univ. (United States)

In this paper, we present a central limit theorem (CLT) for the estimation of a false match rate for a single matching system.

The false match rate is often a significant factor in an evaluation of such a matching system. To achieve the main result here we utilize the covariance/correlation structure for matching proposed by Schuckers (2008). Along with the main result we present an illustration of the methodology here on biometric authentication data from Ross and Jain (2003).

This illustration is from resampling match decisions on three different biometric modalities: hand geometry, fingerprint and facial recognition and shows that as the number of matching pairs grows the sampling distribution for an FMR approaches a Guassian distribution.

These results suggest that statistical inference for a FMR based upon a Gaussian distribution is appropriate.

7667-15, Session 4

C-BET (comprehensive biometrics evaluation toolkit) for multi-order analysis of biometric system performance

D. O. Gorodnichy, National Research Council Canada (Canada)

The paper presents the methodology developed by the Laboratory and Scientific Services Directorate of the Canada Border Services Agency for testing and tuning next-generation biometric systems. The advantages of the developed methodology over industry-offered evaluations are described. Implemented in a toolkit called C-BET, this methodology has been applied in recent testings of the state-of-the-art iris recognition systems, the results of which are presented, and is strongly recommended for reporting the performance of loosely constrained biometrics such as face recognition and stand-off biometrics.

7667-16, Session 4

A definitional framework for the human-biometric sensor interaction model

E. P. Kukula, S. J. Elliott, Purdue Univ. (United States)

Existing definitions for biometric testing and evaluation do not fully explain errors in a biometric system. This paper provides a definitional framework for the Human Biometric-Sensor Interaction (HBSI) model. This paper proposes six new definitions based around two classifications of presentations, erroneous and correct. The new terms are: defective interaction (DI), concealed interaction (CI), false interaction (FI), failure to detect (FTD), failure to extract (FTX), and successfully acquired samples (SAS). As with all definitions, the new terms require a modification to the general biometric model.

7667-33, Session 4

Significance test in operational ROC analysis

J. C. Wu, A. F. Martin, R. N. Kacker, C. R. Hagwood, National Institute of Standards and Technology (United States)

To evaluate the performance of fingerprint-image matching algorithms on large datasets, a receiver operating characteristic (ROC) curve is applied. From the operational perspective, the true accept rate (TAR) of the genuine scores at a specified false accept rate (FAR) of the impostor scores and/or the equal error rate (EER) are often employed. Using the standard errors of these metrics computed using the nonparametric two-sample bootstrap based on our studies of bootstrap variability on large fingerprint datasets, the significance test is performed to determine whether the difference between the performance of one algorithm and a hypothesized value, or the difference between the performances of two algorithms where the correlation is taken into account is statistically significant. In the case that the alternative hypothesis is accepted, the sign of the difference is employed to determine which is better than the other. Examples are provided.

7667-17, Session 5

Iris biometrics

P. J. Flynn, Univ. of Notre Dame (United States)

No abstract available

7667-18, Session 5

Fast and efficient iris image enhancement using logarithmic image processing

N. A. Sazonova, S. C. Schuckers, Clarkson Univ. (United States)

Low quality iris images such as blurry, low resolution images with poor illumination create a challenge for iris recognition systems. Therefore, an efficient enhancement of iris images are needed in challenging environments. We propose a new iris recognition algorithm for enhancement of normalized iris images. Our algorithm is based on the logarithmic image processing (LIP) image enhancement which is used as one of the 3 stages in the enhancement process. Methods are tested on the MBGC database to compare enrolled video iris images from 124 subjects with 220 pixels resolutions to query video portal images from 110 subjects with 120 pixels resolution. Results from processing challenging MBGC iris data show significant improvement in the performance of iris recognition algorithms in terms of equal error rates compared to the original (unenhanced images) and the other fast image enhancement methods.

7667-19, Session 5

Continuous user authentication using temporal information

K. Niinuma, Fujitsu Labs. (Japan); A. K. Jain, Michigan State Univ. (United States)

Conventional computer systems authenticate users only at the initial log-in session, which can be the cause of a critical security flaw. To resolve this problem, systems need continuous user authentication methods that continuously monitor and authenticate users based on some biometric trait(s). We propose three criteria for continuous authentication: usability, security, and cost. These criteria are important both for high-security systems as well as low-security systems. To satisfy these criteria, we propose a new framework for continuous authentication and a new algorithm based on a Webcam that monitors a logged in user's face and color of clothing. Our method can authenticate users regardless of their posture in front of the workstation (laptop or PC). Many studies on continuous authentication use multimodal biometrics, but none of them can identify the user in the absence of biometric observations. To alleviate this requirement, our method uses color information of users' clothing as an enrollment template in addition to their face information. The system cannot pre-register the clothing color information because this information is not permanent. To deal with the problem, our system automatically registers this information every time the user logs in and then fuses it with the conventional (password) identification system. We report preliminary authentication results and future enhancements to the proposed system. Preliminary tests demonstrate that the system is able to continuously authenticate a user in several challenging situations, including posture changes and the presence of other individuals in the camera's field of view.

7667-20, Session 5

Robust human identification using ecg: eigenpulse revisited

D. Jang, S. M. Wendelken, J. M. Irvine, The Charles Stark Draper Lab., Inc. (United States)

Biometrics, such as fingerprint, iris scan, and face recognition, offer methods for identifying individuals based on a unique physiological measurement. Recent studies indicate that a person's electrocardiogram (ECG) may also provide a unique biometric signature. Several methods for processing ECG data have appeared in the literature and most approaches rest on an initial detection and segmentation of the heartbeats. Various sources of noise, such as sensor noise, poor sensor placement, or muscle movements, can degrade the ECG signal and introduce errors into the heartbeat segmentation. This paper presents a screening technique for assessing the quality of each segmented heartbeat. Using this technique, a higher quality signal can be extracted to support the identification task. We demonstrate the benefits of this quality screening using a principal component technique known as eigenpulse. The analysis demonstrated the improvement in performance attributable to the quality screening.

7667-21, Session 5

New biometric modalities using internal physical characteristics

J. H. J. Brooks, General Resonance (United States)

Biometrics is described as the science of identifying people based on physical characteristics such as their fingerprints, facial features, hand geometry, iris patterns, palm prints, or speech recognition. Notably, all of these physical characteristics are visible or detectable from the exterior of the body. These external characteristics can be lifted, photographed, copied or recorded for unauthorized access to a biometric system. Individual humans are just as unique internally, however, as they are externally. New biometric modalities have been developed which identify people based on their unique internal characteristics. For example, "Boneprints" use acoustic fields to scan the unique bone density pattern of a thumb pressed on a small acoustic sensor. Advances in piezoelectric materials allow placement of a small, flexible acoustic sensor in virtually any device such as a steering wheel, door handle, or keyboard. Similarly, "Imp-prints" - which measure the electrical bio-impedance patterns of, for example, the hand and fingers - can verify a person's identity from a stored database. Small impedance sensors can be easily embedded in devices such as smart cards, gun handles, or wall mounts. These internal biometric modalities rely on physical characteristics which are not visible or photographable, providing an added level of security. In addition, both can be combined with physiologic measurements such as acoustic Doppler or impedance plethysmography, providing verification that the biometric pattern came from a living person. These new biometric modalities have the potential to allay user concerns over protection of privacy, while continuing to provide a high level of security.

7667-22, Session 6

Real-time extraction of soft biometrics from surveillance imagery

G. E. Rosenbush, Y. Ran, Q. Zheng, SET Corp. (United States)

Soft biometrics are a practical solution to reduce identification time and to perform coarse authentication of individuals or a group of individuals in unconstrained scenarios. Biometric information derived from height, gait parameters such as cadence and stride length, weight, measurements of body parts, gender, eye color, hair color, age and ethnicity provide candidate filters. In most of the scenarios for indoor/outdoor surveillance using EO or IR sensors, a subset of soft biometrics can be extracted using face and gait data. Likewise, a subset of soft biometric signatures is available from driver's licenses, visa applications, job applications and passports. We have developed a set of real-time algorithms for extracting soft-biometrics from EO or IR sensors. At long range, we extract gait signatures and calculate cadence and stride length. We also use gait signatures to determine gender. At close range, face images are used to classify gender and hair color with a support vector machine approach. From the silhouette, available at medium range, we estimate body size as small, medium, or large build using a second support vector machine. Height is estimated using the target's silhouette and a scene geometry approach. We have evaluated the performance of these algorithms across changes in range, pose, and illumination. In our experiments, fusion of the soft biometrics can increase performance for identifying individuals by about 10% over use of the individual biometrics alone. Our results show promise for the effectiveness of soft biometric extraction as a tool in assisting real-time human recognition systems.

7667-23, Session 6

Automated person categorization for video surveillance using soft biometrics

M. Demirkus, S. Guler, intuVision, Inc. (United States)

We present a prototype video tracking and person categorization system that uses face and person soft biometry features to tag people in databases and for tracking them between cameras. Our approach takes advantage of temporal aspect of video by extracting and accumulating feasible soft biometric features for each person in every frame building a dynamic soft biometry feature list for each tracked person in surveillance videos. We developed algorithms for face and session soft biometry feature extraction to achieve gender and ethnicity classification and to aid in camera hand-off in surveillance videos with low resolution and uncontrolled illumination. To train and test our algorithms we collected over 1500 face images including faces for two gender and three ethnicity groups with varying sizes, pose and illumination. These soft biometry feature extractors and classifiers are implemented on our existing video content extraction platforms to enhance video surveillance tasks. Our algorithms produced promising results with low to medium quality surveillance and broadcast videos in gender and ethnicity classification and tracked person re-identification for camera hand-off. By utilizing the proposed system, a high level description of extracted person soft biometric data can be stored to provide categorical information on people, to create database partitions to accelerate searches in responding to user queries and in tracking people between cameras.

7667-24, Session 6

Gait curves for human recognition, backpack detection, and silhouette correction in a nighttime environment

B. DeCann, A. A. Ross, West Virginia Univ. (United States)

Automated surveillance systems have the inherent objective to recognize the actions of individuals within their field of view. Furthermore, the need for reliable surveillance increases at night when the capability of the human eye to detect anomalies is reduced. While there has been significant efforts in both object detection and classification of individuals through metrology and gait, the majority of research conducted is in a laboratory or daylight environment where the human vision is not mitigated. The aim of this study is to move beyond traditional capture modalities and explore the issues of object detection and human identification at night. To address these issues, a spatiotemporal gait curve that captures the shape dynamics of a moving silhouette is presented. Using the properties of the gait curve, modules are developed for individual classification and backpack detection. Additionally, the notion of silhouette restoration in the presence of objects is explored. Evaluation of these algorithms is conducted on the CASIA Night Gait Database, which includes 10 video sequences each of 153 unique subjects walking perpendicular to the field of view. The video sequences are captured from a low resolution thermal camera. Matching performance is evaluated using a nearest neighbor classifier. The outcome of this study is an efficient algorithm for backpack detection, human identification and a basis for further study in silhouette enhancement.

7667-25, Session 6

An automated process for deceit detection

I. Nwogu, Univ. at Buffalo (United States)

In this paper we present a prototype for an automated deception detection system. Similar to polygraph examinations, we attempt to take advantage of the theory that false answers will produce distinctive measurements in certain physiological manifestations. We investigate the role of dynamic eye-based features such as eye closure/blinking and lateral movements of the iris in detecting deceit. The features are recorded both when the test subjects are having non-threatening conversations as well as when they are being interrogated about a crime they might have committed. The rates of the behavioral changes are blindly clustered into two groups.

Examining the clusters and their characteristics, we observe that the dynamic features selected for deception detection show promising results with a truth detection rate of over 70% from a study consisting of 28 subjects.

7667-26, Session 6

Accurate pose estimation for forensic identification

G. Merckx, J. Hermans, Katholieke Univ. Leuven (Belgium)

In forensic authentication, one aims to identify the perpetrator among a series of suspects or distractors. A fundamental problem in any recognition system that aims for identification of subjects in a natural scene is the lack of constrains on viewing and imaging conditions. In forensic applications, identification proves even more challenging, since most surveillance footage is of abysmal quality. In this context, robust methods for pose estimation are paramount. In this paper we will therefore present a new pose estimation strategy for very low quality footage. Our approach uses 3D-2D registration of a textured 3D face model with the surveillance image to obtain accurate far field pose alignment. Starting from an inaccurate initial estimate, the technique uses novel similarity measures based on the monogenic signal to guide a pose optimization process. We will illustrate the descriptive strength of the introduced similarity measures by using them directly as a recognition metric. Through validation, using both real and synthetic surveillance footage, our pose estimation method is shown to be accurate, and robust to lighting changes and image degradation.

7667-27, Session 7

A study of multibiometric traits of identical twins

Z. Sun, Institute of Automation (China); A. A. Paulino, J. Feng, Michigan State Univ. (United States); Z. Chai, T. Tan, Institute of Automation (China); A. K. Jain, Michigan State Univ. (United States) and Korea Univ. (Korea, Republic of)

The increase in twin births has created a requirement for biometric systems to accurately determine the identity of a person who has an identical twin. The discriminability of some of the identical twin biometric traits, such as fingerprints, iris and palmprints, is supported by anatomy and the formation process of the biometric characteristic, which state they are different even in identical twins due to a number of random factors during the gestation period. For the first time, we collected multiple biometric traits (fingerprint, face and iris) of 66 families of twins and we performed unimodal and multimodal matching experiments to assess the ability of biometric systems in distinguishing identical twins. Our experiments show that unimodal finger biometric systems can distinguish two different persons who are not identical twins better than they can distinguish identical twins; this difference is much larger in the face biometric system and it is not significant in the iris biometric system. Multimodal biometric systems that combine different units of the same biometric modality (e.g. multiple fingerprints or left and right irises) show the best performance among all the unimodal and multimodal biometric systems, achieving an almost perfect separation between genuine and impostor distributions.

7667-28, Session 7

A multibiometric face recognition fusion framework with template protection

S. Chindaro, F. Deravi, Univ. of Kent (United Kingdom)

In this work we present a novel fusion framework based on combining existing unprotected 2D face with 3D face biometrics, which are protected by a privacy enhancing technology that uses error correcting codes and cryptographic primitives (hash functions). The 3D face data is template protected to safeguard the privacy of the users of the biometric system at the same time enabling accurate matching through fusion with 2D, without the need to store the 3D original biometric data.

The integration of 2D face recognition approaches ensures the system is backward compatible with the existing deployed systems. If an unprotected 2D and 3D protected template falls into unauthorized hands, the malicious users may identify the person but it would be difficult, if not impossible for them to use it to gain access, because of the protection offered by the 3D component.

Experiments are conducted to compare the matching performance of such multibiometric systems with the individual biometric channels working alone and with unprotected multibiometric systems. The results show that a 3D face template-protected module, which enhances privacy as well as the performance of existing 2D algorithms, can be effectively integrated into existing 2D systems. The integration of 2D face recognition approaches in the fusion ensures the system is backward compatible with already deployed systems. The system presented is generic and can be used for any combination of biometric algorithms, provided one of the algorithms produces feature vectors which can be protected using the template protection algorithm presented.

7667-29, Session 7

When data goes missing: methods for missing score imputation in biometric fusion

Y. Ding, A. A. Ross, West Virginia Univ. (United States)

While fusion can be accomplished at multiple levels in a multibiometric system, score level fusion is commonly used since it offers a good trade-off between data availability and accessibility.

However, the presence of missing scores will affect the implementation of several biometric fusion rules. Among existing techniques for handling missing data, the imputation scheme, which replace missing values with predicted values, is preferred since the imputation process could be followed by a standard fusion scheme designed for complete data. The focus of this paper is on the performance comparison of three widely known imputation methods: Imputation via Maximum Likelihood Estimation (MLE), Multiple Imputation (MI) and Random Draw Imputation through Gaussian Mixture Model estimation (RD GMM) in the context of score level fusion. A novel method called Hot-deck GMM is also introduced which exhibits markedly better performance than the other methods because of its ability to preserve the local structure of the score distribution.

Experiments on the MSU dataset indicate the robustness of the schemes in handling missing scores at various missing data rates.

7667-30, Session 8

Batch-mode active learning for biometric recognition

S. Chakraborty, V. Balasubramanian, S. Panchanathan, Arizona State Univ. (United States)

Active learning methods have gained popularity to reduce human effort in annotating examples in order to train a classifier. When faced with large amounts of data, the active learning algorithm automatically selects appropriate data samples that are most relevant to train the classifier. Typical active learning approaches select one data instance (one face image, for example) in one iteration of the algorithm, and the classifier is trained with the selected data instances, one-by-one. Instead, there have very recent efforts in active learning to select a batch of examples for labeling at each instant rather than selecting a single example and updating the hypothesis. In this work, a novel batch mode active learning scheme based on numerical optimization of an appropriate function has been applied to the biometric recognition problem. In problems such as face recognition, real-world data is often generated in batches, such as frames of video in a capture session. In such scenarios, selecting the most appropriate data instances from these batches (which usually have a high redundancy) to train a classifier is a significant challenge. In this work, the instance selection is formulated as a mathematical optimization problem and the framework is extended to handle learning from multiple sources of information. The results obtained on the widely used NIST Multiple Biometric Grand Challenge (MBGC) and VidTIMIT biometric datasets corroborate the potential of this method in being used for real-world biometric recognition problems, when there are large amounts of data.

7667-31, Session 8

Assessment of H.264 video compression on automated face recognition performance in surveillance and mobile video scenarios

B. Klare, Michigan State Univ. (United States); M. Burge, MITRE Corp. (United States)

We assess the impact of the H.264 video codec on the match performance of automated face recognition in surveillance and mobile video applications. A set of two hundred access control (90 pixel inter-pupilary distance) and distance surveillance (45 pixel inter-pupilary distance) videos taken under non-ideal imaging and facial recognition (e.g., pose, illumination, and expression) conditions were matched using two commercial face recognition engines in the studies. The first study evaluated automated face recognition performance on access control and distance surveillance videos at CIF and VGA resolutions using the H.264 baseline profile at nine bitrates rates ranging from 8kbs to 2048kbs. In our experiments, video signals were able to be compressed up to 128kbs before a significant drop face recognition performance occurred. The second study evaluated automated face recognition on mobile devices at QCIF, iPhone, and Android resolutions for each of the H.264 PDA profiles. Rank one match performance, cumulative match scores, and failure to enroll rates are reported.

7667-32, Session 8

Ear recognition under partial occlusion based on neighborhood preserving embedding

Y. Li, Z. Wang, Z. Mu, Univ. of Science and Technology Beijing (China)

As a new biometrics authentication technology, ear recognition remains many unresolved problems, one of them is ear occlusion. This paper deals with ear recognition with partially occluded ear images. Firstly, the whole 2D image is separated to sub-windows. Then, Neighborhood Preserving Embedding is used for feature extraction on each sub-windows, and we select the most discriminative sub-windows according to the recognition rate. Thirdly, a multi-matcher fusion approach is used for recognition with partially occluded images. Experiments on the USTB ear image database have illustrated that using only few sub-window can represent the most meaningful region of the ear, and the multi-match model gets higher recognition rate than using the whole image for recogni-tion.

Conference 7668: Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications VII

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Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications VII

3D imaging without range information

J. D. Rogers, D. R. Myatt, Waterfall Solutions Ltd. (United Kingdom)

3D imaging technologies have considerable potential for aiding military operations in areas such as reconnaissance and mission planning through improved data integration and visualisation. This paper describes the development of a real-time system for passively recovering 3D structure from a single electro-optic sensor attached to an aerial vehicle that is, for example, circling a target. By tracking features within the video stream the camera geometry may be reconstructed, along with the associated 3D structure. The integration of this capability into the TIGER system, a larger multi-resolution 3D system for battlefield visualisation, is also detailed.

Development of a low-cost multipurpose imaging architecture capable of high-resolution lock-in imaging

M. Bush, Clear Align (United States)

Lock-in imaging enables high sensitivity imaging in adverse conditions by exploiting a modulated light source and homodyne detection. We report results on a lock in imaging system fabricated from commercial off the shelf parts utilizing standard cameras and a spatial light modulator. Integrating two co-registered focal planes with per-pixel beam steering at kilohertz rates allows for subsequent image processing to enhance the signals in the scene due to modulated illumination. The same information can be used to recover the standard staring image from the same exposure, allowing the modulated scene content to be placed in context without requiring additional exposures. Adjusting the relative phase of the beam steering mirrors allows us to perform a per pixel quadrature lock-in measurement with phase recovery for intrascenic ranging information. By utilizing standard staring imagers and projection display based digital micro mirror devices, the solution is low cost, high resolution, and high fill factor, as compared to systems requiring custom electronics development in the focal plane. Highly sensitive imaging of cooperative targets has applications in IFF, search and rescue, and covert surveillance.

Additionally, the same system architecture can be extended to other applications. Using the DMD as a beam splitter and inserting band pass filters allow the same system to function as a dual band multispectral imager. Using the DMD to switch off bright pixels early in the integration allow high dynamic range imaging in a single exposure. This flexibility presents an opportunity for a single instrument to cover many operational needs.

Chromotomographic imager field demonstration results

D. O'Dell, R. Bostick, M. Hawks, J. Black, R. Cobb, E. Swenson, G. Perram, Air Force Institute of Technology (United States)

A field deployable hyperspectral imager utilizing chromotomography (CT), with a direct vision prism as the dispersive element, has been constructed at AFIT. The AFIT instrument is currently the fastest known direct vision prism based hyperspectral CT imager and is a prototype for a planned spaced based system. The instrument has the ability to capture spectral and spatial data of static and rapidly evolving scenes such as explosions. Employing a simplistic "shift and add" reconstruction algorithm, spectral and/or spatial data of the scene can be recreated. Unlike many other hyperspectral imagers, the AFIT instrument can capture data that can be utilized to recreate spatial and spectral data of a scene in which a transient event occurs during the middle of collection. Reconstructions of spectral and/or spatial data from static and transient scenes and the potential capability to capture hyperspectral data of rapidly evolving events are presented.

Novel hyperspectral imager for lightweight UAVs

H. K. Saari, VTT Technical Research Ctr. of Finland (Finland); B. Delauré, K. Nackaerts, M. Bart, Flemish Institute for Technological Research (Belgium); V. Aallos, C. Holmlund, J. Mäkynen, VTT Technical Research Ctr. of Finland (Finland)

VTT Technical Research Centre of Finland has developed a new miniaturized staring hyperspectral imager with a weight of 350 g making the system compatible with the light weight UAV platforms. The instrument is able to record 2D spatial images at the selected wavelength bands simultaneously. The concept of the hyperspectral imager has been published in the SPIE Proc. 7474. The operational wavelength range of the imager can be tuned in the range 400 - 1100 nm and spectral resolution is in the range 5 - 10 nm @ FWHM. Presently the spatial resolution is 480 x 750 pixels but it can be increased simply by changing the image sensor. The field of view of the system is 20 x 30 degrees and ground pixel size at 100 m flying altitude is around 7.5 cm. The system contains batteries, image acquisition control system and memory for the image data. It can operate autonomously recording hyperspectral data cubes continuously or controlled by the autopilot system of the UAV. The new hyperspectral imager prototype is first tried in co-operation with the Flemish Institute for Technological Research (VITO) on their UAV helicopter. The instrument is configured for the spectral range 500 - 900 nm selected for the vegetation and natural water monitoring applications. The design of the UAV hyperspectral imager and its characterization results together with the analysis of the spectral data from first test flights will be presented at the conference.

Miniaturization of a SWIR hyperspectral imager

C. P. Warren, J. W. Lam, W. R. Pfister, D. M. Even, A. Velasco, J. Naungayan, NOVASOL (United States)

A new approach for the design and fabrication of a miniaturized SWIR Hyperspectral imager is described. Previously, good results were obtained with a VNIR Hyperspectral imager, by use of light propagation within bonded solid blocks of fused silica. These designs use the Offner design form, providing excellent, low distortion imaging. The same idea is applied to the SWIR Hyperspectral imager here, resulting in a microHSITM SWIR Hyperspectral sensor, capable of operating in the 850-1700 nm wavelength range. The microHSI spectrometer weighs 910 g from slit input to camera output. This spectrometer can accommodate custom foreoptics to adapt to a wide range of fields-of-view (FOV). The current application calls for a 15 degree FOV, and utilizes an InGaAs image sensor with a spatial format of 640 x 25 micron pixels. This results in a slit length of 16 mm, and a foreoptics focal length of 60 mm, operating at F# = 2.8. The resulting IFOV is 417 rad for this application,

and a spectral dispersion of 4.17 nm/pixel. A prototype SWIR microHSI was fabricated, and the blazed diffraction grating was embedded within the optical blocks, resulting in a 65% diffraction efficiency at the blaze wavelength of 1200 nm. This spectrometer design is capable of accommodating slit lengths of up to 25.6 mm, which opens up a wide variety of applications. The microHSI concept can be extended to other wavelength regions, and a miniaturized LWIR microHSI sensor is in the conceptual design stage.

7668-06, Session 1

Field calibration of a broadband compact thermal infrared spectrometer for earth science

W. R. Johnson, S. J. Hook, Jet Propulsion Lab. (United States)

We present field results showing excellent performance for a compact 8-12um hyperspectral grating spectrometer using a combination of a Quantum Well Infrared Photodetector (QWIP) and grating based Dyson spectrometer. The Dyson design allows for a very compact and optically fast system (F/1.6). Cooling requirements are minimized due to the single monolithic prism-like grating design. The configuration has the potential to be the optimal science-grade imaging spectroscopy solution for lighter-than-air (LTA) vehicles and unmanned aerial vehicles (UAV) due to its small form factor and relatively low power requirements. The QWIP allows for optimum spatial and spectral uniformity and provides adequate responsivity to allow for near 100mK noise equivalent temperature difference (NEDT) operation across the LWIR passband. These tests are in preparation for the deployment of the Hypserspectral Thermal Infrared Spectrometer (HyTES) which is currently being funded under NASA's instrument incubator program (iip). Test results show NEDT, linearity as well as applicable earth science emissivity target results (Silicates, water) measured in direct sunlight. A vicarious calibration is also performed to derive direct water temperature using a well calibrated transfer radiometer operating simultaneously.

7668-07, Session 2

Multisensor airborne imagery collection and processing onboard small unmanned systems

S. A. Anderson, N. S. Holt, Utah State Univ. (United States); M. L. Wilson, D. C. Linne von Berg, M. R. Kruer, U.S. Naval Research Lab. (United States)

FEATHAR (Fusion, Exploitation, Algorithms, and Targeting for High-Altitude Reconnaissance) is an ONR funded effort to develop and test new tactical sensor systems specifically designed for small manned and unmanned platforms (payload weight < 50 lbs). This program is being directed and executed by the Naval Research Laboratory (NRL) in conjunction with the Space Dynamics Laboratory (SDL). FEATHAR has developed and integrated EyePod, a combined long-wave infrared (LWIR) and visible to near infrared (VNIR) optical survey & inspection system, with NuSAR, a combined dual band synthetic aperture radar (SAR) system. These sensors are being tested in conjunction with other ground and airborne sensor systems to demonstrate intelligent real-time cross-sensor cueing and in-air data fusion. Results from test flights of the EyePod and NuSAR sensors will be presented.

7668-08, Session 2

Use of compact synthetic aperture radar systems to assist with device detection and discrimination

S. A. Anderson, C. P. Knight, N. S. Holt, Utah State Univ. (United States); M. L. Wilson, D. C. Linne von Berg, U.S. Naval Research

Lab. (United States); D. G. Long, Brigham Young Univ. (United States)

NuSAR (Naval Research Laboratory Unmanned Airborne Systems Synthetic Aperture Radar) is a sensor developed under the ONR funded FEATHAR (Fusion, Exploitation, Algorithms, and Targeting for High-Altitude Reconnaissance) program. FEATHAR is being directed and executed by the Naval Research Laboratory (NRL) in conjunction with the Space Dynamics Laboratory (SDL) and FEATHAR's goal is to develop and test new tactical sensor systems specifically designed for small manned and unmanned platforms (payload weight < 50 lbs). NuSAR is a novel dual-band (L- and X-band) SAR capable of a variety of tactically relevant operating modes and detection capabilities. Flight test results will be described for narrow and wide bandwidth and narrow and wide azimuth aperture operating modes.

7668-09, Session 2

Compact survey and inspection day/night image collection and correlation for small unmanned systems

S. A. Anderson, N. S. Holt, A. Bird, Utah State Univ. (United States); M. L. Wilson, D. C. Linne von Berg, E. F. Fleet, U.S. Naval Research Lab. (United States)

EyePod is a combined visible near infrared (VNIR) and long wave infrared (LWIR) suite of imaging sensors developed under the ONR funded FEATHAR (Fusion, Exploitation, Algorithms, and Targeting for High-Altitude Reconnaissance) program. FEATHAR is being directed and executed by the Naval Research Laboratory (NRL) in conjunction with the Space Dynamics Laboratory (SDL) and FEATHAR's goal is to develop and test new tactical sensor systems specifically designed for small manned and unmanned platforms (payload weight < 50 lbs). The EyePod suite consists of two VNIR/LWIR (day/night) gimbals that, combined, provide broad area survey and focused inspection capabilities. Each EyePod sensor suite pairs an HDTV visible EO sensor with a LWIR bolometric imager providing precision geo-referenced and fully digital EO/IR NITFS output imagery. The LWIR sensor is mounted to a custom jitter-reduction stage to correct for high-frequency motion typically found on small aircraft and unmanned systems. Details will be presented on both the wide-area and inspection EyePod sensor systems, their modes of operation, and results from recent flight demonstrations.

7668-10, Session 2

A simulation of wide-area surveillance (WAS) system and algorithm for digital elevation model (DEM) extraction

B. Cheng, Goodrich Corp. (United States)

With the advance in focal plane, electronics and memory storage technologies, wide area and persistence surveillance capabilities have become a reality in airborne ISR. A WAS system offers much more benefits in comparison with the traditional airborne image capturing systems that provides little data overlap both in terms of space and time. Besides, unlike a fix-mount surveillance camera, a persistence WAS system can be deployed anywhere as desired, although the platform has to be in motion, say circling above an area of interest. Therefore, WAS is a perfect choice for surveillance that can provide near real time capabilities such as change detection, target tracking, etc. However, the performance of a WAS system is still limited by the available technologies, the optics that controls the field-of-view, the electronics and mechanical issues that control the scanning, the focal plane data throughput, and the dynamics of the platform all play key roles in the success of the system. It is beneficial to have a simulated version that can capture the essence of the system, and to help provide insights into the design of a system. We propose to build a simulation of a generic WAS system that allows focal plane layouts, scanning patterns, flight

paths and platform dynamics to be defined by a user. The system will generate simulated image data, based on the sensor model, from reference databases (e.g. CIB and DTED). The simulated data will provide a basis for further algorithm development, such as image stitching/mosaic, registration, and geolocation. We will also demonstrate an algorithm to extract the terrain elevation from the simulated data, and to compare that with the original DEM data.

7668-11, Session 3

Airborne sensor integration for quick reaction programs

G. Gosian, K. L. Mason, T. G. Servoss, B. V. Brower, M. F. Pellechia, ITT Corp. (United States)

In this paper we present an approach to integrate sensors to meet the demanding requirements of Quick Reaction Capability (QRC) airborne programs. Traditional airborne sensors are generally highly integrated and incorporate custom sensor technologies and interfaces. Custom solutions and new technologies often require significant engineering to achieve a high technology readiness level (TRL) and to meet the overall mission objective. Our approach differs from traditional approaches in that we aim to achieve an integrated solution through regular review, assessment, and identification of relevant industry "best athlete" technologies. Attention is focused on solution providers that adhere to standard interfaces and formats, incorporate non-proprietary techniques, are deemed highly-reliable/repeatable, and are enable assembly production. Trusted ITT processes and engineering tools/methods that have traditionally been applied to dozens of longer-acquisition space-based ISR programs over 50 years have recently been leveraged to solving airborne Intelligence, Reconnaissance, and Surveillance (ISR) mission challenges. This presentation describes and illustrates key aspects and examples of these techniques solving real-world airborne mission needs.

7668-12, Session 3

High-speed radiometric measurements of homemade explosive detonation fireballs

M. Spidell, K. C. Gross, Air Force Institute of Technology (United States)

Detonation fireball spectral phenomena are often comprised of both selective and continuum radiation and, in some cases, fine detail in the spectral-temporal evolution can be used to estimate key forensic clues including size and chemical composition of the explosive. Recently, a suite of spectrometers, radiometers, infrared imagers, and pressure probes were used to measure homemade explosive detonation signatures. The explosive charges were between 20-100 lbs and were primarily based on nitrate salts. A four-channel radiometer (HgCdTe, 10.34 µm; InSb, 3.80 µm; InGaAs, 2.34 µm; Si, 1.06 µm) observed nine detonations in continuum radiation bands with temporal resolutions of 10 µs. Variations in the shockwave velocity and radiometric peak may be correlated with differences in explosive chemistry and manufacturing. Three-band (InSb, InGaAs, Si) color temperature measurements indicates peak temperatures around 3500 K at 0.10-0.25 ms which cool exponentially within 5-10 ms and corresponds to a decay to background in the Si channel. Two-band (InSb, InGaAs) color temperature measurements suggest an after-burning fireball lasting between 5-30 ms. The fireball cools to ambient within 1-1.5 s. Fireball temperature evolution may be modeled by a pair of double exponentials representing the growth and decay of initial detonation and after-burn temperatures.

7668-13, Session 3

Terrestrial imaging of military test centers

S. D. Fleming, U.S. Military Academy (United States)

Military test centers require detailed site descriptions. Test agencies demand significant written and visual information of test sites in order to facilitate successful test preparation and execution. New terrestrial imaging techniques (360 degree FOV collection) have recently become feasible to collect in the field. Over the past three years, data has been collected in Panama and in Alaska using cameras and video collection techniques. In coordination with the National Geospatial-Intelligence Agency (NGA) and the Army Geospatial Center (AGC), techniques have been developed to meet test agency needs. These techniques include using iPIX and Immersive Media hardward, integrated with global positioning systems, to collect raw field data. Once processed, the products have been integrated with GIS and mapping applications to produce effective visualization tools for test agencies. Current methods of distributing the data are being evaluated and tested. These methods include DVD and internet browser distribution processes.

7668-36, Session 3

An overview of a high performance zoom camera

B. M. McMaster, Corning Tropel Corp. (United States)

An overview of a high performance zoom camera will be presented.

Performance targets including zoom (magnification range), mass, bore sight, space envelope and environment will be discussed. Optical mounting techniques and flexural decoupling of components for large temperature ranges will be presented. Precision trajectory and positioning of multiple moving lens groups will be reviewed. Lead screw decoupling methods providing axial stiffness with radial compliance will be illustrated. A mechanical system interface with high stiffness and thermal compliance for azimuth and elevation adjustments will be given. A review of lessons learned, including lead screw decoupling and aligning multiple static and moving lens groups.

7668-14, Session 4

Moving target detection for multiband pushbroom sensor

B. Cheng, Goodrich Corp. (United States)

A pushbroom MSI sensor collects image data from the ground, parallel to the flight path, at a specific point angle. Images taken at two instances of time usually have a slight offset, and need to be registered so that they can be compared for any changes between the two images. Moving target detection is a special case of change detection that allows the velocity of the moving object to be determined. We propose an algorithm for the detection of moving targets in a multi-band line scanning pushbroom sensor. Ideally, change detection works best when images are of the same bandwidths and are perfectly registered to one another; since differencing the two images automatically removes most of the common background signal. However, this is not always the case, for example the sensor we use has different bandwidths for each band, and since it is a line-scanner it is much more challenging in image registration than a framed-based scanner. In this study, we will use simulated data of same bandwidth to demonstrate the fundamental algorithm of detection and velocity calculation. The velocity calculation is that of distance divided by time; but, depending on the focal plane layout and other operating considerations and conversion between image space to physical units, this calculation is not as simple as it seems. We will also discuss our effort in applying our algorithm to real line-scan imagery, of different bandwidths in the two channels. We will show the extra image processing efforts needed to make it work, and to show some of the test results.

7668-15, Session 4

Robust vehicle detection in low-resolution aerial imagery

S. Sahli, Y. Ouyang, Y. Sheng, Univ. Laval (Canada); D. A. Lavigne, Defence Research and Development Canada (Canada)

Component-based car detection has been successful for ground-based images. In the aerial images with 11.2 cm/pixel resolution, cars can be represented more than simple 2D rectangular boxes, as that with the lower-resolution. One can see large parts such as front hood, roof, trunk, windshield and shadow, but not smaller component. In addition, the components are distorted by low spatial resolution, low color contrast, specular reflection and viewpoint variation. In this paper, we look for robust image features for vehicle detection in aerial imagery. As the scale-invariant feature transform (SIFT) vectors contain information describing the local structure around the keypoints, the Support-Vector Machines (SVM) can classify the SIFT keypoints to those on the cars and on the background with a high classification rate. Furthermore, we apply the new unsupervised clustering algorithm, Affine propagation, to form the SIFT keypoint clusters. The algorithm is iterated until the clusters are smaller than the car. Orientation information contained in the SIFT vectors can help to classify the SIFT keypoint clusters to car body parts. The second feature that we use is the multiscale blobs, resulting from hierarchical color segmentation in the scale-space and providing robust repeatable feature blobs. The blob information is combined with edge features for more robust segmentation. We classify and pairing the windshield blobs and shadow blobs based on their size, aspect ratios and geometrical relations. Finally, the detecting and accounting the cars are achieved by a fusion of the blob and the SIFT cluster information according to their spatial relations.

7668-16, Session 4

Robust component-based car detection and counting in aerial imagery based on the mean-shift color space clustering

Y. Ouyang, Y. Sheng, Univ. Laval (Canada); D. A. Lavigne, Defence Research and Development Canada (Canada)

In the aerial images of 11.2 cm/pixel resolution, the car components which can be seen are large parts of the car body with no more details. Furthermore, the image components are distorted by low spatial resolution, low color contrast, specular reflection and viewpoint variation. We select the mean shift procedure for robust segmentation of the car parts in the color space. Based on the kernel probability density estimation and the gradient ascent optimization the recursive mean shift procedure converges to the nearest stationary point of the probability density function in the feature space for local mode location estimation, mode delineation and clustering. Compared with the multi-scale blob and edge detection the mean shift procedure is a nonparametric process. Only the resolution of the feature space analysis needs to be determined by the user, such that the clustering is robust, efficient, repeatable and independent of the threshold parameters. Its application to the urban aerial images gives satisfactory segmentation results. We then classify the modes of car body parts, windshield and shadow among the segmented regions, based on their corresponding mode location in the color space and the geometrical moment descriptor of the regions. Finally we detect and count the cars by combining them according to their specific spatial relations. Experiment results show an excellent performance.

7668-17, Session 4

Vehicle detection and tracking from wide-area aerial video

J. Xiao, H. Cheng, H. S. Sawhney, Sarnoff Corp. (United States)

Persistent wide area video surveillance using a large field of view sensor system now provides new opportunities and challenges to simultaneously monitor ground traffic activities in a city-size region. This paper presents an approach to detect and track thousands of vehicles from such aerial surveillance videos. Due to the low ground sampling distance and low frame rate, vehicles usually have small size and may travel a long distance between consecutive frames. Using the traditional approaches such as optical flow estimation and motion blob detection, it is difficult to correctly estimate vehicle speed and associate the detected motion blobs between frames. In this paper, we propose a tracking plus detection approach combined with joint probability framework to detect best candidates and minimize the association costs among all targets by combinatorial optimization algorithm. Our tracking plus detection approach is initialized by motion blob and vehicle detection. The detected vehicle will be tracked by a joint probability framework incorporating information such as motion, appearance, and vehicle detection. The tracking approach can significantly reduce the problems such as miss detection or false blob detection association, and it also can provide good blob candidates for the association cost minimization. Finally, we present experimental results to demonstrate the qualitative and quantitative aspects of our work on a large video dataset.

7668-18, Session 4

Automated multiple target detection and tracking in UAV videos

H. Mao, C. Yang, J. Si, Arizona State Univ. (United States); G. P. Abousleman, General Dynamics C4 Systems, Inc. (United States)

In this paper, a novel framework is presented to detect and track multiple targets in UAV videos. Motion trajectory is analyzed to recognize true moving targets, and an overlap rate based data association method is used for tracking. Since the detection and tracking system is based on target's motion, the very first step is to segment foreground moving areas from background in each video frame. This is achieved by background subtraction. And to stabilize the video, a multi-point descriptor based image registration method is performed, where a projective model is accurate enough to describe the global transformation between frames. For each detected foreground blob, an object model is used to describe its appearance and motion information. Instead of immediately recognizing the detected objects to be targets, we track them for some certain frames. And only those with qualified motion pattern are claimed to be targets. In the subsequent tracking process, a Kalman filter is assigned to each tracked target in order to dynamically estimate its position in each frame. Later detected blobs are used as observations to update the state of tracked targets which they are associated to. The proposed overlap rate based data association method takes observations' splitting and merging into account, and therefore is able to maintain tracks more consistently. Experimental results show that the system performs well on detecting and tracking multiple vehicles in UAV videos. Careful consideration given to each component in the system has made the proposed system feasible for real time tracking needs.

7668-19, Session 4

Pan and tilt real-time target tracking

M. A. Akhloufi, Ctr. of Robotics and Vision (Canada) and Laval Univ. (Canada)

In recent years, we see an increase of interest for efficient tracking systems in surveillance applications. Many of the proposed techniques are designed for static cameras environments. When the camera is moving, tracking moving objects become more difficult and many techniques fail to detect and track the desired targets. The problem becomes more complex when we want to track a specific object in real-time using a moving Pan and Tilt camera system in order to keep the target within the image. This type of tracking is important in surveillance applications. When a target is detected, the possibility of automatically tracking it and keeping it within the image until action is taken is very

important for security personnel working in very sensitive sites.

This work presents a real-time tracking system based on particle filters and permitting the detection and continuous tracking of targets using a Pan and Tilt camera platform. A novel and efficient approach for dealing with occlusions is presented. Also a new intelligent forget factor is introduced in order to take into account target shape variations and avoid learning non desired objects. Tests conducted in outdoor operational scenarios show the efficiency and robustness of the proposed approach.

7668-20, Session 4

Directed area search using socio-biological vision algorithms and cognitive Bayesian reasoning

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Volitional search systems that assist a human in searching for specific objects of interest in wide area imagery (e.g., building, specific type of terrain, etc.) need to overcome the main problems present in current manual and automatic approaches. These problems include finding objects hidden in terabytes of information, relatively few pixels on objects, long intervals between interesting regions, time consuming analysis requiring many humans, no a priori representative examples or templates of interest, detecting multiple classes of objects, and the need for very high detection rates (>95% detection rates) and very low false alarm rates (<10 false alarms per square mile). This paper describes a human-centric system to search and locate occurrences of objects or entities of interest from video imagery of large areas. The system takes simple queries from the analyst and then handles these queries with relatively minimum interaction from the analyst and is still capable of finding the queried objects. It is based on a hybrid approach that combines biologically inspired bottom up attention, socio-biologically inspired object recognition for volitionally recognizing targets, and hierarchical Bayesian networks for modeling and representing the domain knowledge. This approach has the benefits of high accuracy detection, low false alarm rates, and can handle both low-level visual information and high-level domain knowledge in a single framework. It would also be capable of using the human analyst as an oracle and improving with time by observing and learning from the interactions, and would be capable of cross frame correlations to stitch together pieces of an entity when they are scattered across frames. Furthermore, the proposed system can either (a) attend and foveate, thus cueing the human's frame of reference to objects that they are interested in monitoring, or (b) conduct a wider and more general search for interesting entities. Such a system would be of immense help for rapid detection and tagging of objects and terrains of interest in many applications (e.g., large area search and rescue efforts).

7668-21, Session 4

A comparative study of four change detection methods for aerial photography applications

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We present four new change detection methods that create a change map from a 3D change probability map. The primary application of interest is aerial photographic applications, where the appearance, disappearance or change in position of objects must be detected with a high success rate in spite of variations in magnification, lighting and background across the image. The methods rely on an earlier derivation of a change probability map. We describe the theory of the four methods, based, respectively, on Bernoulli Variables, Markov Random Fields, Connected Changes, and relaxation-based segmentation and evaluate and compare their performance experimentally on a set of probability maps derived from a aerial photographs.

7668-22, Session 5

Factors related to low-slant angle affecting airborne video interpretability

D. L. Young, Raytheon Intelligence & Information Systems (United States); T. Bakir, Harris Corp. (United States); R. Butto, Jr., Photon Research Associates, Inc. (United States); F. V. Petitti, Raytheon Intelligence & Information Systems (United States); J. Poffenberger, Moriarty and Associates (United States)

Some of the factors affecting airborne video interpretability due to low slant angle are: 1) the variance of the interpretability over the field-of-view; 2) increased probability of occlusion; 3) effect of target orientation; 4) increased distortion due to atmospheric effects; and 5) reduced situational awareness due to perspective distortion. The video interpretability can be measured using the newly developed Video-NIIRS scale. Like NIIRS, the Video-NIIRS is organized by spatial resolution. In addition, each Video-NIIRS criterion includes a temporal component. The expected variation of the spatial component over the Field-of-View (FOV) as a function of slant angle is calculated. The impact of the increased probability of occlusion as a function of slant angle is addressed as an interruption of the Video-NIIRS temporal component. Re-acquisition of the target after an interruption implies the need for identification which can increase the need for spatial resolution. The above remaining factors such as target orientation, reduced situational awareness, and possible saturation scenarios are discussed and preliminary guidelines given to minimize the negative effects of these factors and possible Video-NIIRS modifications for low-slant angle.

7668-23, Session 5

Expanding the dynamic range of short-wave infrared imagery

M. Hansen, Sensors Unlimited, Inc., part of Goodrich Corp. (United States)

Advances have been made in Short Wave Infrared imaging technology to address the most demanding imaging and surveillance applications. Multiple techniques have recently been developed and deployed in Goodrich cameras to improve dynamic range performance in both the digital and analog RS-170 domains. Improvements have been made on multiple levels to give these cameras the unique ability to automatically compensate for changes in light levels of up to 5 orders of magnitude, while improving intra-scenic dynamic range through raw data acquisition techniques. A proprietary, patent pending, form of histogram equalization was developed and electronically implemented as an onboard image enhancement algorithm to further extrapolate scene information for display.

7668-24, Session 5

Real-time refinement of video geo-location through feature tracking and image registration

A. Pope, M. Engebretson, J. B. Gregga, C. Yang, SET Corp. (United States)

We present a novel method for improving estimates of the pose of an aerial video camera by tracking features in video imagery and registering video frames to reference imagery.

Our pose estimation method is based in part on a Simultaneous Localization and Mapping (SLAM) technique that uses an Extended

Kalman Filter (EKF) to integrate image feature tracking information in order to simultaneously estimate both the motion of the camera and the structure of the scene. The technique we use represents scene points in terms of their inverse depth [1], a representation that neatly accommodates large ranges of scene depth and depth uncertainty. In a natural way, it uses distant points to estimate camera rotation and nearby points (or points with large parallax) to estimate camera translation, thus recovering information under a large range of viewing conditions.

We combine this SLAM technique with a geo-registration method that refines estimates of the camera's pose by registering video frames to reference images. A camera pose estimate from the EKF is used to render a perspective view from controlled reference imagery; a video frame is then registered to this view, and those registration results are supplied to the EKF, correcting its estimate of camera pose. Thus the EKF provides a single framework for integrating all measurements, including both optical motion and geo-registration, while the SLAM technique yields scene structure information that can improve geo-registration performance.

We describe how these techniques have been implemented within a software pipeline to produce refined camera pose estimates continuously, in near real time, on commonly available, portable computing hardware. We also describe the implementation's performance as evaluated on a representative set of aerial video data.

[1] Javier Civera, Andrew J. Davison and J.M.M Montiel; "Inverse Depth Parameterization for Monocular SLAM"; forthcoming in IEEE Trans. on Robotics.

7668-25, Session 5

Correction of projective distortion in long image sequence mosaic without prior information

C. Yang, H. Mao, Arizona State Univ. (United States); G. P. Abousleman, General Dynamics C4 Systems, Inc. (United States); J. Si, Arizona State Univ. (United States)

Long image sequence mosaics have wide applications in many areas such as security surveillance, remote sensing, geographical exploration, agricultural field surveillance, virtual reality, digital video, and medical image analysis. A serious issue plaguing the quality of a long sequence mosaic is due to projective distortion: the image frames that are to be transformed and pasted to the mosaic are significantly scaled down and they appear out of proportion in the mosaic. As more frames being transformed, important target information in the image frames can be lost since the transformed images are too small. Some projective distortion correction techniques make use of prior information such as the GPS information embedded in the image or camera internal and external parameters. This paper proposes a new algorithm to reduce the projective distortion without any prior information. Based on the analysis of the mechanism of projective distortion, we approximate the projective matrix that describes the transformation between image frames by an affine model. With Singular value decomposition, we can deduce the affine model scaling factor that is usually very close to 1. By resetting the image scale of the affine model to 1, the transformed image size remains unchanged. Even though the proposed correction introduces some error in image matching, this error is acceptable and more importantly, the final mosaic maintains the original image size after transformation. We demonstrate the effectiveness of the new correction algorithm on two long and real life UAV sequences taken by a UAV on a model airplane. The method is intuitive, effective, and suitable for real-time implementation.

7668-26, Session 5

Information recovery through image sequence fusion under wavelet transformation

Q. He, Mississippi Valley State Univ. (United States)

Because of these limitations of data collection in remote sensing and surveillance systems, the imagery can appear as low-contrast, blurred, and dark from time to time. As a result, the visual performance of these image data is not good and then data analysis cannot be implemented successfully. The image fusion is to recover clear information by integrating multiple images captured from the same scene. Image fusion can reconstruct a highly-resolved image of a scene from a time series of low-resolution images based on image registration between different video frames. Through image fusion, a new image with high-resolution or more perceptive for human and machine is created.

Here, we propose an image fusion approach to recover useful information in surveillance and remote sensing imagery by the fusion of spatially registered images and image sequences. The algorithm is based on a coarse-to-fine strategy, in which a coarsely fused image sequence is first built from the original video data through a shift invariant discrete wavelet transform between a fixed reference frame and every additional frame. The wavelet-based multiresolution fusion improves temporal stability and keeps consistency of the fused sequence in comparison with other fusion methods. It is well known that the median filter is robust to outliers. If we calculate pixel-wise medians in the coarsely fused image sequence, we can restore a refined fused image. Experimental results on surveillance and remote sensing imagery show that our coarse-to-fine image fusion algorithm is not only robust, but also very efficient.

7668-27, Session 5

Real-time unmanned aircraft systems surveillance video mosaicking using GPU

A. Camargo, R. R. Schultz, Univ. of North Dakota (United States)

Digital video mosaicking from Unmanned Aircraft Systems (UAS) is being used for many military and civilian applications, including surveillance, target recognition, border protection, forest fire monitoring, highway traffic control, transmission line monitoring, among others. Additionally, NASA is using digital video mosaicking to explore the moon and planets such as Mars.

In order to compute a "good" mosaic from video captured by a UAS platform, the algorithm must accommodate with motion blur, the frame-to-frame jitter associated with an imperfectly stabilized platform, perspective changes as the camera tilts in flight, as well as a number of other factors. The most suitable algorithms use the Scale-Invariant Feature Transform (SIFT) to detect features consistent between video frames. Utilizing these features, the next step is to accurately estimate the homography motion model between two consecutive video frames, perform warping to properly register the image data, and finally blend the video frames resulting in a seamless video mosaic. All of this processing takes a great deal of computational resources from the CPU, so it virtually impossible to compute a real time video mosaic on a single CPU using today's technology. Modern graphics processing units (GPUs) offer computational performance that far exceeds current CPU technology, allowing for real-time operation.

This paper presents the development of a GPU-accelerated digital video mosaicking implementation and compares it with CPU performance. Our tests are based on two sets of real video captured by a small UAS aircraft owned and operated by the University of North Dakota: the first sequence captured using thermal infrared (IR) microbolometer camera, and the second sequence captured using a color Electro-Optical (EO) camera. Our experimental results show that we can obtain a speed-up of almost 50 times using GPU technology, so real-time operation at a video capture rate of 30 frames per second is feasible.

7668-28, Session 5

A single-view-based framework for skeleton and body shape representation of moving people

M. G. Milanova, Univ. of Arkansas at Little Rock (United States); L. Bocchi, Univ. degli Studi di Firenze (Italy); Z. Cheng, Infoscitex Corp. (United States)

This paper presents a mark-less approach to capture human performance using "optical flow" measurements and elastic labeled silhouettes. The optical flow not only detects the movements but also provides an estimate of the direction and the speed of motion. The proposed representation is based on a self-organizing system designed for learning how to recognize both the characteristic features of the image and their spatial relationship without the need for initializations or special settings. The positions of the units composing the system allow for extracting information on the position and the dynamics of the observed figure. Reported results show how it is possible to identify the skeleton (legs and torso) of the walking subject using four units. It can be observed that the low-resolution skeleton formed by the four units correctly tracks the walking pattern of the two legs, while the upper segment remains centered on the subject body. Our aim is to interpret the deformation parameters of the grid in order to detect the shape or position of the figure and the dynamics of the movement.

7668-29, Session 5

Image exploitation algorithms for reconnaissance and surveillance with UAV

N. F. Heinze, W. Krüger, G. M. Saur, M. Esswein, Fraunhofer-Institut für Informations- und Datenverarbeitung (Germany)

UAV have a growing importance for reconnaissance and surveillance.

Due to improved technical capability also small UAVs have an endurance of about 6 hours, but less sophisticated sensors due to strong weight limitations.

This puts a high strain and workload on the small teams usually deployed with such systems.

To lessen the strain for photo interpreters and to improve the capability of such systems we have developed and integrated automatic image exploitation algorithms.

An import aspect is the detection of moving objects, to give the photo interpreter (PI) hints were such objects are. Mosaiking of imagery helps to gain better oversight over the scene. By computing stereo-mosaics from monocular video-data also 3-d-modells can be derived from tactical UAV-data in a further processing step. A special instrument of gaining oversight is to use multitemporal images of video-sensors with different resolution and to fuse them into one image. This results in a good situation awareness of the scene with a light-weight sensor-platform and a standard video link.

7668-30, Session 5

Temporal fusion for de-noising of RGB video received from small UAV's

A. D. Fischer, 21st Century Systems, Inc. (United States)

Monitoring video sources received from UAVs is challenging in part because of the quality of the video received. Due to the characteristics of the platform, the targets and the environment, the important elements in the scene are not always observable or easily identified. In addition to typical sensor noise, significant video degrading from video transmitted from an airborne platform is caused by electrical activity from the UAV and artifacts introduced during transmission. Interference from other transmitters, analog noise in the embedded avionics, and multi-path effects can corrupt the video signal during transmission, introducing distortion in the video received at the ground. In some cases, the loss of signal is so severe, no information is received in portions of an image frame.

Through temporal denoising, we capitalize on the oversampling in the temporal domain (across video frames), applying a data fusion approach to de-noise the video.

Fusion occurs by straight averaging of the good set of image frames to the current image frame location. If the current image, N, was identified as bad and co-registration between the neighbor frames failed, then the frame location is interpolated. Finally, gaps in the fused image are filled in by information from the mosaic, which contains a running average of all registered good frames.

Our approach operates in real-time with only a single frame latency.

7668-31, Session 5

Research strategy for the electro-optics sensors domain of the Materials and Components for Missiles Innovative Technology Partnership

M. E. Bray, I. Panella, SELEX GALILEO (United Kingdom)

The Materials and Components for Missiles (MCM), Innovation Technology Partnership (ITP) is a research programme supporting research for guided weapons in Technology readiness Levels 1 to 4. The Anglo-French initiative is supported by the DGA and the MoD. There is an aim to foster projects which partner UK and French universities, SMEs and larger companies. The first projects started in January 2008.

MBDA leads the MCM-ITP and are supported in the management by Qinetiq, Selex Galileo, Roxel, Thales, Microturbo and Nexter. Selex Galileo leads Domain 3 of the MCM-ITP which is concerned with Electro-Optic sensors.

The strategy for Domain 3 has identified 4 key themes. These are:

- Better imagery:

- Operational stressing scenarios:

- Low overall through life cost:

- Active & semi-active sensing:

Results from the following three projects will be presented:

- Conformal Optics

Selex, Qioptic and Element 6 collaborated to evaluate performance improvements by an aerodynamic dome shape allowed by novel optics.

- Super-resolution.

MBDA and Selex worked together to develop a software test-bed to evaluate the performance of various super-resolution algorithms.

- Wavefront Coding.

Selex, Qioptiq and MBDA teamed to compare conventional and wavefront coded seeker designs.

7668-32, Poster Session

Description and evaluation of a vehicle tracking system for multimodal UAV-captured video data

D. A. Sadlier, N. E. O'Connor, Dublin City Univ. (Ireland)

This paper details and evaluates a system for tracking vehicles in aerial video footage captured by UAVs. The subject of UAV object tracking is well studied in the field of computer vision, with various solutions offered. However, rigorous evaluation is infrequent, and further novelty lies here in our exploration of the benefits of combined modality processing, and

a proposed adaptive feature weighting technique. Moving vehicles are initially located by exploiting their intra-scene displacement within a camera-motion compensated video-image domain. For each detected vehicle, a spatiogram-based representation is then extracted - a representative form that aims to bridge the gap between the coarseness of histograms and the rigidity of pixel templates. Spatiogram-based region matching then ensues for each vehicle, towards determining their locations throughout the subsequent frames of the video. The framework is flexible in that, as well as exploiting visible spectrum features, it can accommodate the inclusion of additional feature sources, demonstrated here via the attachment of an infrared channel. In addition, the system features the option of enabling an adaptive feature weighting mechanism, whereby the transient ability of certain features to occasionally outperform others is exploited in an adaptive manner, to the envisaged benefit of increased tracking robustness. The system was developed and tested using the DARPA VIVID2 video dataset. Evaluation of the system is quantitative, which differentiates it from a large portion of the existing literature, whilst the results observed serve to further reveal the challenging nature of the problem.

7668-33, Poster Session

Application of Retnix wavelet moment features for complex illumination

J. He, B. Sun, Beijing Normal Univ. (China)

Since actural application of Target Recognition is offen under outdoor natural circumstances, extence and variance of illumination can not be neglected obviously. Thus, common target recognition algorithm being utilized to images with diverse illumination, efficiency has been studied in the article. The authors have applied Retinex Theory mend on the target recognition algorithm based on wavelet moment. Applying the mended algorithm to marine images, experimental results have shown us a notably optimizing effect.

7668-34, Poster Session

Improved VCA in hyperspectral image processing

J. He, X. Zhu, Beijing Normal Univ. (China)

In recent decades, hyperspectral Images (HSI) have been widely exploited in many fields for rich information containing in them. Many algorithms have been brought out for endmember extracting, among which, VCA algorithm performs a better precision and lower complexity. However, endmembers of the same HIS extracted with traditional VCA algorithm are not always the same in different runs. After deeply analyzing, the authors have proposed an improved VCA algorithm to resolve that shortcoming. For verification, experiment and comparative study have been performed. On conclusion, the improved VCA algorithm has manifested higher efficiency and accuracy than the traditional one.

7668-35, Poster Session

Cross delay line sensor characterization

I. J. Owens, D. K. Remelius, J. J. Tiee, S. E. Buck, S. R. Whittemore, D. C. Thompson, R. Shirey, Los Alamos National Lab. (United States)

There exists a wealth of information in the scientific literature on the physical properties and device characterization procedures for complementary metal oxide semiconductor (CMOS), charge coupled device (CCD) and avalanche photodiode (APD) format detectors. Numerous papers and books have also treated photocathode operation in the context of photomultiplier tube (PMT) operation for either non imaging applications or limited night vision capability. However, much less information has been reported in the literature about the characterization procedures and properties of photocathode detectors with novel cross delay line (XDL) anode structures. These allow one to detect single photons and create images by recording space and time coordinate (X, Y & T) information. In this paper, we report on the physical characteristics and performance of a cross delay line anode sensor with an enhanced near infrared wavelength response photocathode and high dynamic range micro channel plate (MCP) gain (> 10^6) multiplier stage. Measurement procedures and results including the device dark event rate (DER), pulse height distribution, quantum and electronic device efficiency (QE & DQE) and spatial resolution per effective pixel region in a 25 mm sensor array are presented. The overall knowledge and information obtained from XDL sensor characterization allow us to optimize device performance and assess capability. These device performance properties and capabilities make XDL detectors ideal for remote sensing field applications that require single photon detection, imaging, sub nano-second timing response, high spatial resolution (10's of microns) and large effective image format.

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Radar Sensor Technology XIV

Developing a small multifrequency synthetic aperture radar for UAS operation: the SlimSAR

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The SlimSAR's design and testing are presented, representing a new advancement in high-performance, small, low-cost, multi-frequency synthetic aperture radar (SAR) idea for use on unmanned aircraft systems (UAS). ARTEMIS employed a unique design methodology that exploits previous developments in designing the SlimSAR to be smaller, lighter, and more flexible, while consuming less power than typical SAR systems. The compact design is facilitated by using a linear-frequency-modulated continuous-wave signal to achieve high signal-to-noise ratio while transmitting with less power. A delayed mix-down chirp is used to sidestep swath-width limitations. The flexible control software allows us to change the radar parameters in flight. The system is designed with an L-band core, an X-band add-on, a built-in high quality GPS/IMU motion measurement solution (for motion compensation and image geo-location), a commercially available small CDL data link, and a gimbal for the X-band antennas, all weighing less than 20 lbs and consuming less than 150 Watts, making it very suitable for use on a number of small UAS. Development is in progress to add UHF and Ku-band capabilities. The designed operational capabilities include day and night imaging through smoke, dust, rain, and clouds, shallow dry ground penetration at L-band, and change detection at X-band. This paper details the unique SlimSAR system design and the corresponding performance trade-offs. To demonstrate the capabilities of the SlimSAR, example imagery is included.

Airborne ground penetrating imaging radar operating at L-band

R. S. Gordy, D. P. Markell, Global Technical Systems (United States)

The reported airborne SAR radar is capable of detecting buried targets and tunnels over vast areas. Global Technical Systems (GTS) developed a solid state Synthetic Aperture Radar (SAR) that does this task using strip map processing. The radar collects data in three antenna settings: vertical, port, and starboard side with a 40 degree look-down angle. The radar image resolution is 1 meter in range and cross range and operates from 1250MHz to 1400MHz. The roll stabilized phased array antenna has fourteen columns and four rows of elements driven by six 1.2kW solid state power amplifiers. The net ERP of the antenna is 3.5kW. The RF receiver is capable of receiving both a transmit reference and radar returns. The digital modulator generates a chirp waveform and is capable of omitting user defined frequency sub-bands to prevent interference with other L-Band assets. The radar data processing is done with a state-of-the-art correlator using an FPGA processor. The I and Q range data is pre-processed and stored in an airborne RAID. System status and limited SAR imaging is displayed in flight while final SAR imaging and targeting is performed on the ground by the Portable Tactical Analysis (PTAC) unit.

An unattended, unmanned, and man-portable ground sensor for wide-area persistent surveillance

D. Tahmoush, U.S. Army Research Lab. (United States)

Detecting humans and distinguishing them from natural fauna is an important issue in security applications. In particular, it is important to detect and classify people who are walking in remote locations and transmit back detections over extended periods at a low cost and with minimal maintenance.

We develop and demonstrate a compact radar technology that is scalable to a variety of ultra-lightweight and low-power platforms for wide area persistent surveillance as an unattended, unmanned, and man-portable ground sensor. Several different technologies are brought together to develop a small unattended X-band radar. Small, surface-mount RF components are being used to build miniature, low-power transmitter and receiver circuits. An integrated digital signal processor generates range-Doppler maps and uses micro-Doppler processing to eliminate false detections. Detections will be sent onto the network for remote operations. The system is designed to run indefinitely using a combination of power saving operational modes and a solar panel.

We discovered several important characteristics that should be considered in the development of radar systems that utilize the measurement of human and animal micro-Doppler, especially for the reduction in false-positive detections. First, radar which illuminates parts of the human body separately is capable of distinguishing more structure in the micro-Doppler because of the decreased interference from other body parts. Second, a low Doppler resolution can be sufficient for measuring micro-Doppler, though higher is recommended for improved differentiation of fauna and humans. Third, the direction of motion of the target can be critical, but a higher elevation angle can be used to avoid the difficulties experienced when the motion of the targets is perpendicular to the beam of the radar.

This paper will present the system and data on humans and animals at multiple angles and directions of motion, as well as multiple PRFs and frequencies.

Radar system on a large autonomous vehicle for personnel avoidance

J. Silvious, U.S. Army Research Lab. (United States); R. Wellman, General Technical Services (United States); D. Tahmoush, J. Clark, U.S. Army Research Lab. (United States)

The Army Research Laboratory has designed, developed and tested a novel switched beam radar system operating at 76 GHz for use in a large autonomous vehicle to detect and identify roadway obstructions including slowly-moving personnel. The performance requirements for the system to operate in an early collision avoidance mode to a range of 150 meters and at speeds of over 20 m/s will be discussed. The system must also operate in a vehicle follower mode. The measured capabilities of the system to operate in these modes under various conditions, such as urban and rural environments, and on various terrains, such as asphalt and gravel, will be presented. Range-Doppler map processing capabilities developed to correct for platform motion and identify roadway vehicles and personnel moving at 1 m/s or more along the path of the system will be discussed.

7669-05, Session 1

C- and Ku-band dual-frequency multi-polarization combined scatterometer-radiometer system for sea, land, and atmospheric remote sensing

A. K. Arakelyan II, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia)

In this paper a developed C-, and Ku-band, dual frequency, multi-polarization, combined, short-pulse scatterometer-radiometer system is described, for short (from low altitude platform), middle (from vessel) and long (from aircraft) distance remote sensing applications for water surface, soil and land snow cover's microwave reflective and emissive characteristics simultaneous and spatially coincident measurements.

The main technical characteristics of the radiometer-scatterometer system are:

Central frequencies - 5.6GHz (C-band) and 13.6GHz (Ku-band);

Antenna - a parabolic antenna of 50cm of diameter;

Radar pulses durations - 25ns any of frequency band;

Pulse power (controlled) - 50mW-1W for C-band, and 50mW-2W for Ku-band;

Polarization:

Radar Sensing - "vv"; "vh"; "hv"; "hh";

Radiometric Sensing - "v" and "h",

Scatterometer receiver's threshold sensitivity - ~130dB/W;

Radiometer's sensitivities (at 1s) - ~0.1K for C-band, and ~0.2K for Ku-band;

A block diagram of the developed system, as well as time series of scatterometer and radiometer channels operation and control signals of some microwave and low frequency elements of the system will be represented.

The originality of the developed system is in the spatial-temporal combination of dual frequency, microwave active and passive channels of observation and its possible application for short distance remote sensing (the minimum operational ranges of the system's scatterometers are ~3.5m).

7669-06, Session 2

Concept of operation and preliminary experimental results of the DRDC through-wall SAR system

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Mapping the interior of buildings is of great interest to military forces operating in an urban battlefield. Through-wall radars have the potential of mapping interior room layout, including the location of walls, doors and furniture. They could provide information on the in-wall structure, and detect objects of interest concealed in buildings, such as persons and arms caches. We are proposing to provide further context to the end user by fusing the radar data with LIDAR images of the building exterior.

In this paper, we will present our system concept of operation, which involves a vehicle driven along a path in front of a building of interest. The vehicle is equipped with both radar and LIDAR systems, as well as a motion compensation unit. We will describe our ultra wideband through-wall L-band radar system which uses stretch processing techniques to obtain high range resolution, and synthetic aperture radar (SAR) techniques to achieve good azimuth resolution. We will demonstrate its current 2D capabilities with experimental data, and discuss the current progress in using array processing in elevation to provide a 3D image. Finally, we will discuss the potential advantages of fusing radar and LIDAR data.

7669-07, Session 2

A novel technology for fast detecting and imaging subsurface tunnels

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The vast majority of clandestine tunnels "has been found by accident or human intelligence, none by technology" [US News, 2009]. Ground-Penetrating Radar (GPR) is currently the leading Electromagnetic (EM) method that used to spot tunnels, but reliable detection of small air-filled tunnels is a challenging problem for GPR due to low anomalous signal and the masking effect of wet soil. Therefore, there is a need for new types of measurements along with robust data interpretation algorithms. We suggest a new EM method that we predict performs better than GPR in terms of depth of penetration and sensitivity to deep tunnels. This method is based on vertical focusing of the EM field. Low-frequency EM pulses excite the earth surface, and the transient responses are measured during the off-time by the quadrupole receivers. A similar measurement configuration has been successfully tested in oil exploration [Davydycheva et al., 2009]. We present results of 3D modeling performed on a set of benchmark models for both the proposed and the GPR methods. The models were designed using parameters of the recently discovered border tunnels. The feasibility study results indicate that our approach provides a superior resolution for detecting small (1x1m) tunnels. Our findings are that it is unlikely that GPR would have been able to detect these tunnels. We also discuss some technical aspects of design and implementation of a mobile border patrol unit equipped with an array of EM sensors and automated inversion-based data interpretation software (e.g., [Frenkel, 2006]). Such a unit would be able to perform border monitoring and fast mapping of subsurface tunnels.

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7669-08, Session 2

An aggregate modeling and measurement approach for power estimation of through-the-wall target returns

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With recent advances in both algorithm and component technologies, through-the-wall sensing and imaging is emerging as an affordable sensor technology in civilian and military settings. One of the primary objectives of through-the-wall sensing systems is to detect and identify targets of interest, such as humans and cache of weapons, enclosed in building structures. Effective approaches that achieve proper target radar cross section (RCS) registration behind walls must exploit a detailed understanding of the radar phenomenology, in general, and more specifically, knowledge of the expected strength of the radar return from targets of interest. In this paper, we investigate the effects of various wall types on the received power of the target return through the use of a combined measurement and electromagnetic modeling approach. The RCS of material-exact rifle and human models are investigated in free-space using numerical electromagnetic modeling tools. A modified radar range equation, which analytically accounts for the wall effects, including multiple reflections within a given homogeneous or layered wall,

is then employed in conjunction with wideband measured parameters of various common wall types, to estimate the received power versus frequency from numerically modeled aforementioned targets of interest. The proposed technique is, in principle, applicable to both bistatic and monostatic operations. The results for various wall types, including drywall, brick, solid concrete and cinder block, under both wet and dry conditions, are presented.

7669-09, Session 2

Multipath analyses of moving targets in enclosed structures using Doppler radars

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In urban sensing applications, nonstationary targets, such as humans, walk or move next to interior or exterior walls of rooms and buildings. In using Doppler radars, returns from the target are accompanied by multipaths which are represented by reflections from the human body in the directions of sidewalls and floors.

In this paper, we assume that the radar is observing a moving target inside an enclosed room or beside a close wall. For simplicity, we consider only adjacent walls, noting that the extension of the analyses provided for multipaths to other walls is straightforward. The target of interest is assumed to be moving, and without loss of generality, the radar is assumed to be stationary and Doppler based. In the first part of our analyses, we consider a point target, and then extrapolate our treatment to the more realistic case of an extended target. The wall thickness and the wall material are assumed to be known a priori. Using a rigorous reflection coefficient analyses and ray tracing approach, we conclude that it is sufficient to consider the first and second order wall reflections to analyze the multipath. The paper shows a distinction between the multipath Doppler signature and that of the direct Doppler, which manifests itself in non-overlapping spectra. This implies that the use of multipath excision filters can be effective in separating the direct path and the multipath Doppler components. The paper includes both computer simulations and experimental results supporting its conclusions.

7669-10, Session 3

Evaluation of images from space-borne SAR systems

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In 2007 several space borne SAR-Systems have been launched e. g. TerrSAR-X, Cosmo SkyMed, Radarsat 2, ALOS, ... and are delivering many high quality SAR images for different fields of applications. Interesting application are summarized under the term security. Especially the information related to high spatial resolution of the sensors is of common interest.

In the first part the paper gives a short overview of the sensor parameters relevant for the image quality. Characteristic image examples will be demonstrated for a detailed analysis. In the second part of the presentation possible evaluation criteria will presented and discussed for the appropriate application. Examples of analysis schemes can be derived from the different versions of the National Image Interpretation Rating Scale (NIIRS), or other public catalogue derivatives based on geospatial intelligence services. In the third part of the paper a detailed analysis based on image quality parameters, e. g. spatial resolution, radiometric resolution, noise equivalent sigma zero, integrated sidelobe ratio, ... will be carried out. Each analysis example will be demonstrated by corresponding illustrative image material.

7669-11, Session 3

Dual-use RF-based sensing for proximity and space weather event detection

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We propose an RF-based space situational awareness (SSA) system that provides proximity sensing and hazardous space weather sensing. In our approach, we use wide band antennas to transmit an outgoing ping and in return utilize the beam forming capability to detect the incoming wavefront from potential scattering points for proximity sensing. Similarly we simultaneously send and receive from an antenna pair and characterize the communication channel to ascertain the amount of ambient disruption to determine presence of hazardous space weather.

Optical based techniques have several drawbacks when operating in space with obvious problems in lighting and heat dissipation affecting both visible and infrared imaging. Our approach is a simplified synthetic aperture technique that can also act as a communication medium for which we determine baseline operations. We leverage characteristics of space debris which appear as rough pieces of metal with a large number of reflectors. Power consumption and detectability of small debris will certainly place a severe limitation on our approach to which we intend to leverage our multi-source capability to provide sufficient signal power for small object detectability. Several space phenomena involve charged particle streams with known plasma frequencies within our RF bandwidth. Their presence results in a disruption of communication channels. We model these characteristics in our baseline calculation and indicate the presence of space weather when the baseline deviates from our normal operation. We can then utilize this to place the space asset in a hardened state to minimize damage all within sub-second response time.

7669-12, Session 3

Airborne cable detection with a W-band FMCW imaging sensor

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Numerous accidents occur each year due to wire strikes for both military and commercial helicopters leading to a significant number of fatalities. Even on a clear day, power lines and tower cables are difficult to detect and identify with the human eye from close distances. The millimeter-wave sensor is an ideal potential solution because it can see the very small attributes of the typical power line/cable wire as well as operate when visual conditions worsen due to environmental issues such as fog, smoke or dust. This paper presents recent results on the development of a W-band FMCW imaging sensor with potential application to cable detection and imaging. The W-band sensor front end is integrated with a radar signal generator, processor, and data acquisition unit for the purpose of closing the loop between prototype demonstration and ongoing development. Real-time imaging is achieved at a 10 Hz frame rate with a field of view of +/-15o. A twist reflector antenna provides a fan beam with 0.65o x 4.0o beam resolution (azimuth x elevation). A completely integrated front end unit was developed and mounted to a Honeywell AStar helicopter to demonstrate the flight-worthiness of the sensor under close to actual operational conditions. Real-time imaging results demonstrate detection capability and potential to identify individual cables with fine range resolution. The development of such technology that can detect and avoid obstacles such as cables and wires especially for rotorcraft platforms will save lives, assets, and enable the execution of more complex and dangerous tactical missions.

7669-13, Session 3

A computer simulation of a CWFM radar showing the tradeoffs of performance as a function of range

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CWFM is a modulation type that gives a short range radar exceptional performance with low power transmitters. The radar simulation reported here has a 5 Watt and 10 Watt transmitter. It is a Ka-Band radar with an operating bandwidth of 500 MHz giving it a capability of producing Synthetic Aperture Images with a resolution in range and cross range of 1 foot. A description of the simulation and the performance curves are presented, giving a good basis for a detail design.

A description of the CWFM modulation and detection method is given as a functional block diagram and the simulation of the radar is performed using SystemView. A range of 10 miles is modeled to cover the performance used in small Unmanned Airborne Systems. Radar cross sections of 1 square meter, 10 square meters, 200 square meters, and 1,000 square meters are used to calculate the detection range with a Pd= 0.75 and Pfa = 10-5. This provides an estimate of the minimum discernable signal. Arguments are given for the use of CWFM for short range rather than long range.

7669-14, Session 3

A velocity independent continuous tracking radar concept

D. L. Bickel, D. W. Harmony, A. Martinez, Sandia National Labs. (United States)

This paper presents a novel concept for tracking a moving object with a radar system through all phases of the object's motion. The concept involves gathering and processing the raw radar data into various products at video rates. The various products are "tuned" to the different velocity ranges of the object. These various products are then fed into the tracking algorithms and the radar is guided to maintain illumination of the object at all times. The authors will present preliminary results from data collected with the Sandia National Laboratories' Ka-band radar system.

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7669-15, Session 4

I see the Rayleigh problem ... it's everywhere

J. E. Gray, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

Phase noise is ubiquitous, it occurs in many settings where randomness occurs in the sensor measurement process that involves radars or other types of sensors. The wide occurrence of phase noise problems that frequently occur in many different radar applications are all instances of the Rayleigh problem. It occurs everywhere. The problem arose in Lord Rayleigh's investigations of scattering of acoustical waves off of rough surfaces. We mention 40+ different instances of the Rayleigh problem and then briefly discuss how the solution can be mathematically characterized using the characteristic function of the probability density function of superposition of random variables of phase and amplitude. We illustrate the mathematics of the solution with a number of examples that are of interest in the sensor community.

7669-16, Session 4

A study on compressed-sensing based sampling techniques for ultra-wideband (UWB) radar

L. H. Nguyen, U.S. Army Research Lab. (United States); T. D. Tran, The Johns Hopkins Univ. (United States)

The Army Research Lab has recently developed an ultra-wideband (UWB) synthetic aperture radar (SAR) that has been employed to support proof-of-concept demonstration for several concealed target detection programs.

The radar transmits and receives short impulses that cover the frequency spectrum from 300 MHz to 3000 MHz. From basic sampling theory, in order to satisfy the Nyquist sampling requirement, very high speed analog-to-digital converters (A/D) are required to directly digitize these time domain signals. However, it is too costly to build high speed ADC converters that can directly digitize the wide-bandwidth returned signals. Therefore, ARL has developed a sampling technique that allows us to employ inexpensive A/D converters to digitize the wide-bandwidth signals. This technique is called Synchronous Impulse Reconstruction (SIRE), which is a modified and enhanced version of the equivalent-time sampling technique widely used in commercial digital storage oscilloscopes and other radar systems.

In this paper, we briefly describe the current sampling scheme. Although we have successfully implemented the SIRE acquisition technique, the drawback of any time equivalent sampling technique is the longer time requirement to complete a data acquisition cycle. This in turn translates to lower average power and lower effective pulse repetition frequency (PRF). Thus, we have conducted a study on an alternative and more efficient time-equivalent sampling scheme that is based on the recently emerging compressed-sensing theory in the signal processing community. We provide an in-depth analysis of the proposed sampling scheme and study the trade-offs between time and signal reconstruction performance.

7669-17, Session 4

Improving the fast back projection algorithm through massive parallelizations

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With sensor technologies rapidly improving, the need to process increasingly larger data sets is becoming the main bottleneck in many real time applications associated with persistence surveillance such as VideoSAR and volumetric SAR imaging. In many instances, the image fidelity is of utmost importance which can have implications when choosing the appropriate algorithm to generate the desired data products. The performance improvements afforded by algorithms such as the fast back projection (FBP) algorithm prove attractive for such environments. Unfortunately, even though the FBP algorithm is magnitudes faster than a traditional back projection algorithm it is still incapable of meeting the strict requirements of some of the aforementioned real time applications. However, the emergence of general purpose graphical processing units (GPGPUs) in recent years have afforded many scientific fields orders of magnitudes improvement in performance for a large variety of applications. This is also the case for the FBP algorithm. By distributing the processing across 480 processing cores located on a single video card, it possible to achieve substantial performance improvements compared to the serial FBP algorithm. Considering that many PCs are capable of housing three to four video cards, it is possible to obtain more than two orders of magnitude improvement in performance with the parallel approach. This technology provides the ability to process enormous datasets in the field without the need of supercomputers that have to date been the only means of keeping pace with the incoming data.

7669-18, Session 4

MIMO target modeling with heterogeneous sensor nodes

J. Park, The Ohio State Univ. (United States); A. K. Mitra, Air Force Research Lab. (United States); M. Qiu, Univ. of Kentucky (United States); J. T. Johnson, The Ohio State Univ. (United States)

We discuss the analysis and design of distributed radar systems using commercially available narrowband wireless sensor nodes. As part of the initial discussion on potential applications for RF sensor nodes for the development of future radar systems, we provide a tabulation of RF system parameters for commonly available wireless sensor nodes. The basic philosophy behind the development of our design methodologies allows for the comparative evaluation of data quality and detection performance based on performance tradeoffs associated with a number of realistic sparse sensor-node geometries. All of the candidate sensor geometry structures adopted for this investigation are heterogeneous in the sense that a single relatively higher power transmitter is assumed (i.e. somewhat analogous to a base station) along with several low-power distributed wireless receiver nodes. The wireless receiver nodes are position-adaptive in the sense that the analysis is performed under the assumption that each of these nodes spatially cover a small localized angular sector within a given geometrical category. The size and spatial distance covered in the neighborhood of the receive nodes is also a major parameter that is documented as part of this geometrical trade study of radar performance using narrowband RF sensor node technology. Some of the distributed radar system performance metrics are reported via the extraction of scattering centers from Matlab code that we developed for purposes of simulating distributed radar system imaging performance for canonical scatterers such as trihedrals. As part of this performance evaluation and tradeoff-based design process, we also simulate the electromagnetic response of a desired set of canonical scatterers corresponding to a given geometrical category. In the summary section, we also include a short discussion on potential follow-on research and additional future applications for this type of technology.

7669-19, Session 4

Channel-warped impulse propagation functions

A. K. Mitra, Air Force Research Lab. (United States)

Over the last fifty years or so of radar history, one observable trend in the evolution of radar technologies involves transition from, for example direct data display systems such as PPI (Plan Position Indicator) to the consideration of somewhat more sophisticated research systems that implement adaptive processing on the receiver front-end. Implementation of these type of intermediate pre-display filtering procedures on the receive data have shown good potential for improving the performance of SAR (Synthetic Aperture Radar), GMTI (Ground Moving Target Indication), and joint SAR/GMTI systems. Within the past few years, more recent advances in technology including advances leveraged from the commercial wireless industry show potential for the development of technologies that are jointly adaptive on both transmit and receive. Many of these advances will be enabled on future radar systems due to new capabilities for generating adaptive transmit waveforms via the design and implementation of low-cost DDS-like (Direct Digital Synthesis) signal generators. This paper discusses some potential approaches to developing next-generation radar technologies via the development of smart hardware subsystems that have the intrinsic capability to compensate for channel warping and propagation distortions. In other to characterize and model typical categories of propagation distortions, a series of sample calculations are provided with respect to modeling/estimating atmospheric channel distortions and warping at a number of millimeter-wave radar frequencies. Gaussian impulse excitation waveforms and Double-Debye scattering parameters are adopted for the analysis. Comparative results are tabulated by mapping the Double-Debye scattering parameters to significant categories of environmental

scattering conditions at millimeter-wave radar frequencies. The objective is to explore potential approaches to developing state-of-the art digital, RF, and optical technologies with intrinsic smart compensation capabilities that will enable the development of high-resolution radars that can operate at longer ranges while maintaining compact size and weight requirements.

7669-20, Session 4

A new coherent processing algorithm for combined subband radar imaging

X. Xu, J. Li, BeiHang Univ. (China)

The problem of radar imagery from sparse frequency subbands initially incoherent to each other is of practical importance. The major challenge for this lies in two aspects. First, for high resolution radar image to be formed, accurate coherent processing must be conducted among all the incoherent subbands. Second, the data gaps between subbands must be filled or special image processing algorithms be applied. Different techniques were proposed for gapped data imagery in previous work. Subband coherent processing, however, was rarely studied.

In this work, we propose a new coherent processing technique for combined subband radar imaging from two or more initially incoherent radar subband measurements. To complete, the coherence parameters (CPs) are obtained by combining modern spectral analysis with probability density estimation (PDE), thus enabling more robust cohering for the sparse subband data of real-world complex targets. Simulated subband imaging results from both anechoic chamber and airborne synthetic aperture radar (SAR) data for real-world target are presented to demonstrate the usefulness of the proposed technique.

The paper consists of four sections: 1. Introduction; 2. Subband Coherent Processing Procedure; 3. Statistical Technique for Cohering Parameter Estimation; 4. Simulation Results and Analysis; and References.

7669-21, Session 5

A real-time high-resolution optical SAR processor

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An optical SAR processor prototype exhibiting real-time and fine sampling capabilities has been successfully developed and tested. Synthetic Aperture Radar (SAR) images are typically processed digitally applying dedicated Fast Fourier Transform (FFT) algorithms. These operations are time consuming and require a large amount of processing power and are often performed in one dimension at a time. A true two dimensional Fourier transform may be instead performed through optics, as optical processing provides inherent parallel computing capabilities. By processing the azimuth and slant range directions simultaneously, a reduction in processing time and power is achieved. In addition, the configuration of the optics is such that high resolution images may be obtained at no additional processing cost. The optical SAR processor is also designed to adapt to SAR system parameter changes. It has the capability to process full ENVISAT / ASAR image mode raw data sets from the various swaths (IS1 - IS7) in a matter of seconds. Sampling distances are nominally finer than digital processing sampling distances for both the azimuth and slant range directions.

This paper reviews the design of the real-time high resolution optical SAR processor prototype and discusses the results of images reconstructed from simulated point targets as well as from ENVISAT / ASAR data sets.

7669-22, Session 5

Compact low-cost high-sensitivity CMOS radar-on-chip integration for security applications

C. Li, Texas Tech Univ. (United States); J. Lin, Univ. of Florida (United States)

Based on the measurement results of a recently fabricated 5 GHz CMOS radar sensor microchip, it will be shown that low power CMOS radar-on-chip integration can have high detection sensitivity despite the large flicker noise and phase noise contributions around the signal of interest. Several key technologies to further improve the integrated radar sensitivity will be evaluated based on measurement and simulation results. To eliminate the leaked baseband spectral noise caused by DC offset due to CMOS device mismatch, software configured DC offset calibration loop will be proposed. To suppress the integrated noise at the analog-to-digital converter (ADC) input, a tunable baseband bandwidth limiter will be evaluated for the detection of movement in different frequency/velocity ranges. To solve the problem of high flicker noise in CMOS process, special receiver architecture will be introduced.

Other possible improvements on the overall desirability of radar sensor chip will also be discussed, including Extremely High Frequency (EHF) integration in Ka-band and 60 GHz band, on-chip antenna integration, and multi-mode operation (i.e. motion sensing and data communication) for full system integration.

The advantages of CMOS radar-on-chip solution are low-cost, low power, small size, and ease of covert operation. It will be shown that the high-sensitivity potential of CMOS on-chip radar makes it suitable to detect very small movement in millimeter range. The application of low-cost CMOS integrated radar will be focused on surveillance and reconnaissance, sensing through-wall radar, ground penetration radar, homeland security, border monitoring, and moving target detection.

7669-23, Session 5

Antenna analysis using properties of metamaterials

A. K. Mitra, Air Force Research Lab. (United States); K. Maxwell, Univ. of Dayton (United States); C. Hu, Beavercreek High School (United States)

As part of the Student Internship Programs at Wright-Patterson Air Force Base, including the AFRL STEP Program and the AFRL Wright Scholar Program for High School Students, the characteristics of a number of fractal antenna geometries are reviewed. Basic analysis and design characteristics for a selective set of fractal antennas are provided including the Koch curve, the Hilbert curve, and the Sierpinski gasket. In addition, a review of the state-of-the-art with respect to a number of related technologies such as RF MEMS (Micro-electromechanical Systems) Technologies for Fractal Antennas are provided. The second portion of the paper introduces the reader to a number of important properties for a class of materials known are Metamaterials. These metamaterials have generated a considerable amount of interest in the past few years and show potential for the development of future RF devices that can be designed in more integrated and compact forms. The third section of this paper is intended to initiate discussions on the potential for combining fractal antenna geometries with recent advances in metamaterials to obtain potential advances in antenna technologies such as more compact size over a given frequency range. Approximate equivalent circuit models for both fractal antennas and metamaterials are employed for this analytical section of the paper. The final section of the paper discusses the feasibility of fabricating and testing some of the resulting joint fractal/metamaterials-based antenna structures and cites some potential avenues for further research. Potential applications that may support future radar and wireless system development requirements are also discussed.

7669-24, Session 5

Ultra-compact optical true time delay device for wideband phased array radars

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An ultra-compact optical true time delay device is demonstrated that can support 112 antenna elements with better than six bits of delay in a volume 13"x5"x2.5" excluding the box and electronics. Free-space beams circulate in a White cell, overlapping in space to minimize volume. The 18 mirrors are slow-tool diamond turned on two substrates, one at each end, to streamline alignment. Pointing accuracy of better than 10μrad is achieved, with surface roughness ~45 nm rms. Short delays (delay increment is 312.5 ps) are implemented in high-index rods (ZnSe and silicon), long delays in folded mirror trains. A MEMS tip-style mirror array selects among the paths for each beam independently, with switching time of <100 μs to switch the whole array. The micromirrors have 1.4°tip angle and three stable states (left, right, and flat). The input is a fiber-and-microlens array, whose output spots are re-imaged multiple times in the White cell, striking a different area of the single MEMS chip in each of 10 bounces. The output is converted to RF by an integrated InP wideband optical combiner detector array. Delays were accurate to within 4% (shortest delay) to 0.03% (longest mirror train). The fiber-to- detector insertion loss is 6.6 dB for the shortest delay path.

7669-25, Session 5

Demonstration of shifter-less beam steering in an ultra-wide bandwidth array antenna using synchronized chaos

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We demonstrate a new method for electronic beam steering in ultra-wide bandwidth array antennas based on synchronized chaos. Chaotic oscillators generate random-like waveforms that may be well-suited for highly unconventional ultra-wideband radar and spread-spectrum communication applications. The broadband and non-repeating nature of chaos provides an ideal combination of high range resolution with no range ambiguity. Unlike true random sources, coupled chaotic oscillators can synchronize for coherent power combining. To steer the array, a small detuning is applied to each oscillator to slightly shift its natural frequency. Oscillators that are tuned to run faster will lead those tuned slower, providing a small time shift between the waveforms produced by each oscillator. The approach avoids the need for costly phase shifters or tunable true time delay elements. Our demonstration system consists of a linear array of four directionally coupled radio frequency chaotic oscillators, each of which produces a broadband waveform centered at 130 MHz. Each individual oscillator feeds one of four omnidirectional, discone-type antennas spaced a half wavelength apart. The physical placement of the four antenna array and the receive antenna was arranged to minimize multipath components. We present far-field power level measurements characterizing beam formation and steering recorded on an outdoor test range. Our results suggest chaotic microwave arrays could enable a new generation of low-cost, high-performance, ultra-wide bandwidth applications.

7669-49, Session 5

On a new seeker gimbal

M. E. Rosheim, Ross-Hime Designs, Inc. (United States)

Increasing use of precision directional sensors has added the need for mechanical manipulators that can point seniors accurately and precely anywhere in a desired workplace. Singularities in the dynamics of such manipulators, or loss of-degree-of-freedom in the workspace, due both to conditions in the physical structure or in control software used in the control system provided therefore, often impede the performance of mechanical manipulators in reaching these goals. Presented is a revolutionary missile seeker gimbal that features extended range of motion and singularity free operation. Due to the new and unique kinematics of the gimbal architecture an increase in over one-hundred percent the sensor surface area is featured. Improved isolation from shock and vibration are by-products of the innovative kinematics. Named the Super-Seeker it is designed for the Joint Air Ground Missile (JAGM) under current development for U.S. Army Space Missile Defense Command at Redstone Arsenal.

7669-27, Session 6

Noise correlation radar

M. Govoni, U.S. Army RDECOM (United States); H. Li, Stevens Institute of Technology (United States)

This work investigates the feasibility of using noise to amplitude modulate a chirped radar waveform without impacting the modulated signal's ability to resolve stationary and moving targets. The waveform being transmitted is neither a pure noise signal nor a modulated noise signal as is the case with Random Noise Radar (RNR) and Random Signal Radar (RSR), but rather one that's comprised of both noise and chirped waveform. This unique combination gives way to a newly defined noise radar class referred to by the authors as Noise Correlation Radar (NCR). By introducing the noise envelope, we show that our waveform arrives at some unique advantages not found in conventional chirped radar waveform and coincidently, some noise radar waveform as well. Results were generated from computer simulation and demonstrate that the proposed waveform possesses the same characteristics found in the aforementioned radar classes with the addition of several distinct advantages. Figures are included to illustrate how the transmit spectrum of our noise modulated chirped waveform assumes an ideal ambiguity function while acquiring a "masked" transmit spectrum. It is also shown that the addition of the noise modulating signal does not negatively impact the pulse compression gain derived from the chirped signal.

7669-28, Session 6

Generation of high-range resolution radar signals using the Lorenz chaotic flow

B. C. Flores, C. S. Pappu, The Univ. of Texas at El Paso (United States)

We propose a novel approach to generate Frequency Modulated (FM) signals with applications in high-resolution radar imaging. The technique relies on the output of an n-dimensional (n>2) non-linear system that exhibits chaotic behavior. For simplicity, we have chosen the Lorenz system which has a set of three state variables x, y and z, and three control parameters , , and . FM signals are generated using anyone of the state variables as the instantaneous frequency by varying the values of and . We demonstrate that the obtained FM signal is ergodic and stationary and that the time samples exhibit an invariant probability density function. The corresponding pseudo-phase orbits reveal themselves as a strange attractor that may take on the shape of a Mobius strip, disc or an extended disc, depending on the time evolution of the signal. A time-frequency analysis of the signal shows that the spectrum is centered on a time-dependent carrier frequency. Thus, the

FM signal has a high time-bandwidth product similar to that of a chirp. However, the carrier frequency continuously shifts in a linear or quadratic pattern that folds over many times due to aliasing. A desirable feature of the signal is that the width of its autocorrelation's mainlobe approaches the reciprocal of the bandwidth. Furthermore, the sidelobe distribution of the autocorrelation typically falls below -18 decibels and decays quickly.

7669-29, Session 6

Effects of using a first-order approximation to compensate the Doppler on large time-bandwidth product signals

H. A. Ochoa, P. Vutukur, The Univ. of Texas at Tyler (United States)

The next generation of radar systems is currently being researched to improve resolution and performance. A common approach to achieve this is by increasing the Time-Bandwidth (TBW) product of the signal that is being transmitted. The current generation of radar systems uses a first-order approximation to compensate for the frequency shift generated by the target's velocity. The issue with this method is that the first order approximation is composed only by the first two terms of a power series expansion. As a consequence, any increase in the TBW product of the signal results in significant errors. Some schemes propose a relativistic analysis of the scattered signal to create a full Doppler compensation of the signal instead of using a first-order approximation [1][2]. In this research, in order to analyze the effect of using a first-order approximation the echo obtained from a moving target is modeled by using a linear frequency modulated (chirp) pulse with a large TBW product. Then the echo is applied as an input of a matched filter and the output is analyzed. The effects produced by the first-order approximation are observed by increasing the TBW product of the transmitted signal and by comparing these outputs with the output obtained when a signal with a regular time-bandwidth product is considered. In summary, we are modeling echo signals with large TBW product and comparing the outputs generated by these signals with the outputs generated from signals with regular TBW products.

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7669-30, Session 6

Waveform design for detection of weapons based on signature exploitation

F. Ahmad, M. G. Amin, Villanova Univ. (United States); T. Dogaru, U.S. Army Research Lab. (United States)

In typical radar operational environments, the possible targets considered in the scene of interest are known in advance. Sufficient a priori information about the properties and characteristics of these targets, such as the target shape, size, and composition, is available. The goal of the radar system is to detect the presence of the target of interest and to determine its location. Waveform design techniques based on target signature exploitation make use of the a priori information for improved target detection.

In this paper, we specifically focus on the matched illumination signature exploitation concept in which the transmit pulse shape is designed such that it maximizes the signal-to-interference-and-noise-ratio (SINR) at the output of the receiver matched filter. We consider an AK-47 rifle as the target of interest and assume ground based monostatic radar operation. We analyze the changes in the target signature content as a function of the aspect angle using both experimentally measured and

electromagnetically modeled target scattering responses over the 1-6 GHz frequency range. The target features are identified and categorized into those highly dependent on the target orientations and others insensitive to aspect angles. Optimal matched illumination detection waveforms for various aspect angles are presented which incorporate the respective AK-47 signatures. These single aspect angle waveforms are shown to be sensitive to the difference between the assumed and true target aspect angles. Waveform design that exploits the target underlying signature characteristics which persist over a wide range of aspect angles is also investigated. In this case, unlike the aforementioned deterministic approach, we model and analyze the target signatures as random processes and perform SINR-based waveform optimization.

7669-31, Session 6

Remote sensing of wireless devices

D. King-Smith, Purdue Univ. (United States); A. Martone, U.S. Army Research Lab. (United States)

Remote detection and characterization of wireless devices in an environment is a topic of growing importance. Characterization of a wireless device is useful in many applications. An example of this is the use of wireless devices in restricted areas. These devices must follow strict guidelines to minimize RF interference. Forensic techniques can be used to characterize and locate wireless devices. We present a framework for remote detection and forensic characterization of RF devices using specially designed probe signals. This framework can be applied to a broad range of devices and models. Probe signals, device models, feature selection, classifier design are described. For the device model we introduce a method for simulating a nonlinearity in the RF system based on a known diode model. Experimental results are given to verify our approach.

7669-50, Session 6

Characterization of RF front-ends by long-tail pulse response

G. Mazzaro, K. I. Ranney, Army Research Lab. (United States)

No abstract available

7669-33, Session 7

Synthetic aperture radar imaging of moving targets using monopulse radar

R. M. Naething, The Univ. of Texas at Austin (United States) and Sandia National Labs. (United States); D. L. Bickel, Sandia National Labs. (United States); S. M. Buckley, The Univ. of Texas at Austin (United States)

Synthetic aperture radar (SAR) is a technique that forms coherent images of objects based on their radio reflectivity. SAR systems have many diverse applications, including radar imaging, topographical mapping of the earth surface, navigation and guidance, and environmental monitoring. SAR technology offers advantages over optical imaging because of its ability to image through inclement weather and to penetrate foliage and ground. Fine resolution is achieved in range through signal bandwidth (most often through the use of a chirped pulse), and in cross range (or azimuth) through a synthesized aperture much larger than the physical antenna of the imaging device. Proper focusing requires knowledge of the relative motion between the sensor and the imaged object. Consequently, unknown target velocity, acceleration, rotation, and vibration introduce a variety of errors in the image.

The work addresses a novel method of focusing a moving target in a SAR image through the estimation of various motion parameters. The target cross-range position is determined through monopulse radar, at which

point range velocity and acceleration are estimated across a series of overlapping subapertures. Cross-range velocity is then estimated through a search to optimize an image quality metric such as entropy or contrast. A final focused image is then generated based on this velocity vector.

This technique is demonstrated with both synthetic and real radar data, and the performance of this technique is compared both subjectively and with a variety of image metrics to the MITRE keystone technique.

7669-34, Session 7

Utilizing the microASAR on the SIERRA UAS for NASA's characterization of Arctic sea ice experiment

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The microASAR builds on the design of the BYU uSAR, but is a much more robust and flexible system. The microASAR is a complete, self-contained SAR system that has been designed specifically to be small and lightweight while still being robust and capable. This makes it ideal for use on unmanned aircraft systems (UAS) and other small aircraft.

The NASA SIERRA (Sensor Integrated Environmental Remote Research Aircraft) UAS is a medium class, medium duration aircraft designed by the Navel Research Laboratory to test new instruments and support NASA earth science flight experiments. The SIERRA is ideal for deployment in remote areas where manned flight is dangerous. With the capacity to carry multiple payloads, the SIERRA is suitable for a variety of missions.

The Characterization of Arctic Sea Ice Experiment 2009 (CASIE-09) combines the use of a variety of remote sensing methods, including satellite observations and UAS, to provide fundamental new insights into ice roughness on the scale of meters to tens of meters in the context of larger-scale environmental forcing. In addition, the mission offers a technological and operational testbed to demonstrate the value of autonomous vehicles for long-range, long-duration remote sensing science. Five science flights covering 2923 km of sea ice were flown in July 2009.

This paper summarizes the design of the microASAR, its integration onto the NASA SIERRA UAS, and its role in the CASIE mission. The success of the Arctic deployment is illustrated with results including microASAR imagery and data from other sensors on-board the SIERRA.

7669-26, Poster Session

An improved slotted ground plane antenna for wide-beam high-gain applications

H. Zhao, Zhengzhou Univ. of Light Industry (China)

With the development of the satelaite navigation,positioning and communication systems ,there are ever-increasing demands on the coverage and the low elevation gain . In order to get the weak satellite signals quickly, generally require the antenna has a broad beamwidth and can maintain a low angle of elevation gain.

Various slot antennas have been introduced for different applications. In these,the CP antenna designed with 2 pairs of slot embedded on its ground plane has advantages,such as better CP,compact size ,simple structure, low cost and ease of construction.The peak gain for the antenna measured is around 2dBm,and 3dB beam width is around 95°.

In this Letter, an improved design of the slotted ground planer antenna is proposed. High permittivity dielectric material is used for substrate of the antenna,and reduce the size of the ground plane, to achieve a wider 3dB beamwidth.Its 3dB beamwidth can be as wide as 140°.While the

coverage of high dielectric constant material layer on the slot antenna,the experimental results shown that the gain measured is 4dB higher than the antenna as mentioned above,so the gain has been significantly improved.By adjusting the length of the slotted pair ,two orthogonal near-degenerate resonant modes centered at 1575MHz for CP radiation can be exited on the square patch of the proposed antenna.So the improved antenna also maintain the advantages of the original.

It is important to make wide-beam and high-gain radiation patterns of CP microstrip antennas,which not only can be used in GPS,but also can be used in wide-angle scanning phased array.

7669-45, Poster Session

Iterative sidelobe reduction in transmission-constrained stepped frequency synthetic aperture radar

K. I. Ranney, L. H. Nguyen, U.S. Army Research Lab. (United States); J. P. Sichina, Delaware State Univ. (United States)

Researchers at the Army Research Laboratory (ARL) have recently developed an iterative technique for improving image quality in ultrawideband (UWB) radar systems. This technique, dubbed "recursive sidelobe minimization" (RSM), has been applied extensively to data sets in which no constraints have been placed on the amount of transmitted bandwidth. That is, no frequency notching was required prior to transmission of the waveform. In this paper we describe an extension of the earlier RSM technique designed to reduce the artifacts introduced by frequency notching. We include results obtained applying the technique to both simulated and measured data.

7669-46, Poster Session

Modeling of pulse-to-pulse radar return for extended targets

C. T. Inaebnit, M. John, Armasuisse (Switzerland)

Relative movement between antenna phase center(s) and target causes changes in the aspect direction during the coherent processing interval (CPI). For a target of given size in terms of wavelength the width of the corresponding angular interval determines if the target can be considered as point-like or must be modeled as extended target. In contrast to the case of high-resolution SAR/ISAR imaging systems, where the width of the angular interval is sufficient to obtain a fine resolution of the target, the paper is focused on the case where the target extends only a few resolution cells in the cross-range direction. For the latter case deterministic and stochastic target models for detection and classification are presented and illustrated by means of data derived from backscattering measurements in an indoor range.

The target models are derived from a mixed representation of monostatic backscattering in the combined aspect angle and spatial domain (similar to time-dependent spectrum) where the width of the angular window and spatial resolution are exchangeable. For a "very small" width of the angular window the target is point-like and deterministically characterized by its scattering amplitude (matrix in case of polarimetric radar) and the correponding centroid position. With increasing width of the angular window the target becomes extended and can e.g. be characterized by means of a set of central moments or by a few discrete scattering centers. For modeling the CPI pulse-to-pulse return ("radar signature") for a family of tracks across the two-dimensional aspect angle domain a stochastic processes are allocated to these models.

7669-47, Poster Session

Estimation of far-field radar properties of targets from measurements taken in the scattering near field

C. T. Inaebnit, M. John, Armasuisse (Switzerland)

In order to evaluate and to model the radar properties of targets of particular interest indoor backscattering measurements of the targets with varying aspect directions and frequencies are carried out by armasuisse. Subsequently, a linear backprojection algorithm (SAR/ISAR in scattering near-field) is employed to reconstruct a 3-D-image of the target. With regard to the utilization of the obtained complex valued reflectivity function for an estimation of the radar returns under operational far-field conditions two novel processing schemes will be presented and verified by means of experimental results (X-Band).

The first processing scheme is a near-field CLEAN procedure. Since for the successive extraction of point scatterers from the 3-D-image the properties of the measurement set-up can fully be taken into account, distortions in the original 3-D-image with respect to the scattering magnitude and sidelobes are largely removed in the extracted ensemble of point scatterers.

Whereas the ensemble of point scatterers is determined to reproduce the data measured in the scattering near-field, modeling of radar properties under operational conditions requires information about backscattering for much higher distances between sensor and target (e.g. far-field condition). Examples for properties to be modeled under operational conditions are RCS-PDF for selected aspect angle domain, pulse-to-pulse covariance during CPI, angular glint in tracking etc.

Since a rigorous conversion of monostatic near-field backscattering data into far-field data is principally impossible, a method which provides under certain conditions the best approximation should be employed. For this purpose a method was developed which describes near-field imaging by means of spatially varying local aspect directions and reconstructs the far-field data via a deconvolution in the aspect angle domain.

7669-48, Poster Session

Near-field EM scattering calculation for target-seeker encounter simulation

M. Sui, X. Xu, BeiHang Univ. (China)

In many electromagnetic (EM) scattering applications, high-frequency asymptotic scattering prediction techniques have been widely used, especially for electrically large objects. Most published papers on high-frequency techniques are mainly concerned with the far-field scattering computation, while field distribution in the near field region is of importance as well. Several attempts have been made to refine standard physical optics (PO) techniques through employing a more accurate representation of the Green function for near-field computation. An approach taken by Pouliguen et al. and Neto relies on an exact Green function. While achieving excellent accuracy, this method requires numerical integration of the surface currents, which is highly undesirable for electrically large objects. Recently, Legault's work preserves the simplicity of standard PO formulation and resolves such difficulty by means of a phase approximation with an expansion center that lies in the neighborhood of the source of interest.

By introducing the concept of distinct wave propagation vector, this paper proposes a formulation of modified PO and Michaeli's equivalent edge currents (EEC) to be adaptable for near-field computation. Moreover, this method can easily be generalized for other high-frequency scattering prediction techniques, which is attractive for application s as in target-seeker encounter simulation and other applications. We arrive at exactly the same formula as yielded in Legault's work. While Legault presented more rigorous mathematical formulation and phase error analysis, this paper provides an alternative interpretation of the key formula based on the distinct wave propagation vector concept, which is

much easier to understand.

The paper consists of five sections: 1. Introduction; 2. Distinct Wave Propagation Vector; 3. Modified Physical Optics; 4. Modified Equivalent Edge Currents; 5. Numerical Results and Analysis; and References.

7669-36, Session 8

Persistent GMTI surveillance: theoretical performance bounds and some experimental results

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The detection of slow ground moving targets over short coherent processing intervals is possible via clutter cancellation using stationary linear filtering techniques referred to as space-time adaptive processing (STAP). The detection output of STAP are then fed to a tracker for the estimation of (possibly nonstationary) moving target parameters.

The switched mode nearly constant velocity model provides a good state model for the movers. In addition, the filtering and smoothing performance of the Bayesian filter is a function of the measurement model, which is a subset of range, angle and Doppler measurements. Several filtering techniques can be employed, such as the (multiple model variants of) EKF, particle filters, etc., with varying degrees of robustness in performance, and computational requirements.

The radar measurement errors are a function of the radar parameters---e.g., the angle estimation error is a function of the number of apertures. The Cramer-Rao lower bounds (CRLBs) are derived for the different subsets of measurement models. The simulated performance of the various Bayesian filters are then compared against the CRLB in a wide range of realistic operational scenarios, e.g., for typical airborne radar parameters, ground moving target manoeuvres, missed detections and probability of false alarms. The impact of different measurement model noise on target parameter estimation is assessed.

DRDC Ottawa's XWEAR radar is a reflector-based two-channel GMTI radar that utilizes a multi-mode feed-horn. The performance of the various Bayesian filtering algorithms, based on the detections obtained using STAP on real data, are compared against the ground truth.

7669-37, Session 8

SAR-based vibration retrieval using the fractional Fourier transform in slow time

Q. Wang, M. Pepin, B. Santhanam, The Univ. of New Mexico (United States); T. D. Atwood, Sandia National Labs. (United States); M. M. Hayat, The Univ. of New Mexico (United States)

Recent reports on the effects of vibrating targets on synthetic-aperture radar (SAR) imagery and the potential of SAR to extract the non-stationary signatures have drawn significant interest from the remote-sensing community. SAR returned signals are the superposition of the transmitted pulses modulated by both static and non-static targets in amplitude and phase. More precisely, the vibration of a target causes a small sinusoid-like frequency modulation in slow time, whereby the frequency deviation is proportional to the instantaneous velocity of the vibrating object. By means of successive small segments in slow time, each frequency modulated pulse can be tracked and further approximated as a piecewise-linear frequency modulated signal. The discrete-time fractional Fourier transform (DFRFT) is an analysis tool geared toward signals containing linear frequency modulated components. Within each segment, the DFRFT transforms each frequency modulated component into a cone in the DFRFT plane, and the peak position of each cone corresponds to the frequency modulation rate. A series of such measurements provide the instantaneous-velocity history and its spectrum bears the vibrating signature of the target. Additionally, when the chirp-z transform (CZT) is incorporated into the DFRFT, vibration-induced modulations can be identified with high

resolution. In this work, the interplay amongst SAR system parameters, vibration parameters, the DFRFT's window size and the CZT's zoom-in factor is characterized analytically. Simulations were also conducted to verify the analysis. The results show that the detection of vibration frequency using the slow-time approach is significantly more sensitive than that obtained using a previously reported fast-time approach.

7669-38, Session 8

Clustering analysis of moving target signatures

A. F. Martone, K. I. Ranney, R. Innocenti, U.S. Army Research Lab. (United States)

In previous research, we have developed and evaluated a moving target indication (MTI) processing approach that detects and tracks slow-moving targets inside buildings using data collected by our low-frequency, ultra-wideband radar. Our MTI processing suite includes change detection (CD), automatic target detection (ATD), clustering, and tracking algorithms. CD is used to identify the moving target signature. ATD is used to eliminate imaging artifacts and potential false alarms due to target multi-bounce effects. The clustering algorithm is used to identify a centroid for each cluster present in the ATD output images. Finally, the tracker is used to establish a trajectory of the moving target. Most recently we have developed a Pixel Finding (PF) algorithm to automatically identify the number of clusters present in the ATD output images thereby automating our MTI approach. The PF algorithm is analogous to the image processing, pixel labeling procedure. In this paper we use the PF algorithm in conjunction with the MTI processing algorithms to process data collected by our low-frequency, ultra-wideband radar. We then analyze the output images produced by the clustering algorithm and evaluate the effectiveness of the PF algorithm.

7669-39, Session 8

Quantization of polarization states through scattering mechanisms

G. Stratis, A. Samuel, S. Bellofiore, Raytheon Missile Systems (United States); A. Taflove, A. Katsaggelos, Northwestern Univ. (United States); C. Penney, Remcom, Inc. (United States); G. C. Maalouli, Raytheon Missile Systems (United States)

In this paper, we introduce a new technique that relates the split of polarization states with various scattering mechanisms. We use the finite-difference time-domain (FDTD) method in our computations since, by its nature, FDTD can model an ultrawideband source and can separate the various scattering mechanisms by exploiting causality. The key idea is that, once a non-monochromatic wave is incident upon a scattering object, the various spectral components will be differently depolarized upon scattering depending upon the shape and material composition of the object. In the case studied here, all of the impinging spectral components are co-polarized (whereas arbitrary polarization distributions are permitted more generally). Fundamentally, we are exploring a concept similar to the split or quantization of energy states in quantum mechanics. We first introduce the concept of the quantization of polarization states, and then we explain the formulation of the "State Space Matrix" in relationship to the polarization gaps. Once the technique is introduced, we demonstrate its potential applications to realistic problems such as materials detection.

7669-40, Session 8

Adaptive detection of range-spread targets by the generalized detector

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we address an adaptive detection of range-spread targets or targets embedded in Gaussian noise with unknown covariance matrix by the generalized detector based on the generalized approach to signal processing in noise. We assume that cells or secondary data that are free of signal components are available. Those secondary data are supposed to process either the same covariance matrix or the same structure of the covariance matrix of the cells under test. In this context, we design the generalized detectors according to the generalized approach to signal processing and use a two-step design procedure. The criteria lead to receivers ensuring the constant false alarm rate (CFAR) property with respect to unknown quantities. A thorough performance assessment of the proposed detection strategies, together with the evaluation of their processing cost, highlights that the two-step design procedure of decision-making rule in accordance with the generalized approach to signal processing in noise is to be preferred with respect to the plain one. In fact, the proposed design procedure leads to generalized detectors that achieve significant improvement in detection performance under several situations of practical interest. For estimation purposes, we resort to a set of secondary data. In addition to the classical homogeneous scenario, we consider the case wherein the power value of primary and secondary data vectors is not the same. More precisely, both groups of data separately satisfy the homogeneity condition, but the two covariance matrices coincide only up to a scaling factor. The design of adaptive detection algorithms based on the generalized approach to signal processing in noise in case of mismatch is a problem of primary concern for radar applications. In fact, although most of the space-time adaptive processing detection schemes have been designed employing the assumption that interference returns were independent and identically distributed Gaussian vectors, experimental campaigns have demonstrated that such an assumption is not always verified. Analysis of several space-time adaptive processing algorithms, mostly conducted assuming homogeneity of the secondary data, has shown that inhomogeneities magnify the loss between the adaptive implementation and optimum conditions. We demonstrate that two-step design procedure based on the generalized approach to signal processing in noise ensures minimal loss.

7669-41, Session 9

A study of human body radar signature variability based on computer models

G. A. Kirose, T. Dogaru, U.S. Army Research Lab. (United States)

Radar detection of human dismounts has been a long standing problem of interest for the U.S. Army. This interest was renewed during the last decade in the context of asymmetric warfare, as attested by numerous DoD radar programs that focus on detection of human targets both in the open or concealed behind walls or vegetation. Studying the human body radar signature is an important prerequisite in the design and performance prediction of such systems. The electromagnetic modeling research group at the Army Research Laboratory (ARL) has done an extensive analysis of the human body signature based on computer models.

This paper investigates the variability of the human body radar signature, for both stationary targets (where we are interested in the radar cross section) and moving targets (where we are interested in the Doppler response). In the past, we have been looking at only one or two human models, in one walking pattern, with variation of geometric parameters such as the aspect angle. The approach in this paper involves mesh distortion and various walking patterns, in order to predict changes in the radar signature induced by morphological changes in the human meshes. As mentioned, the study is based entirely on computer simulations. We start with a basic human mesh and use the Maya software package to articulate or distort the model. Realistic human motion animation

is obtained by using coordinates of body markers recorded for real subjects in walking motion. The radar signature is obtained by running an FDTD-based electromagnetic solver. Results are presented as radar cross section for stationary targets or Doppler spectrograms for moving targets.

7669-42, Session 9

Phenomenology of fully polarimetric SIR-C data

J. V. Geaga, Consultant (United States)

We have completed the analysis of single look fully polarimetric data from SIR-C. The analysis of multilook fully polarimetric data was reported at the SPIE Radar Sensor Technology XIII conference in April 13-15, 2009. The title of the paper is Stokes Matrix Eigenvectors of Fully Polarimetric SAR Data. In addition to the property that only one of the eigenvectors of the Stokes Matrix satifies the condition for a Stokes Vector, the eigenvector solutions for the single look data are fully polarized (no depolarized part). An interesting relationship between the eigenvalue and span for a pixel will be shown. Results from the investigation of the copolarized phase difference distributions for the ocean surface, lake surface, lake ice, bare ground, crop fields and vegetation are reported. Consideration of high resolution data from such sensors as RADARSAT 2, TerraSAR-X and aircraft data will allow for detailed modeling studies of fully polarimetric signatures.

7669-43, Session 9

Simulating spaceborne X-band polarimetric SAR observations of precipitation using ground-based S-band weather radar data

J. P. Fritz, V. Chandresekar, Colorado State Univ. (United States)

Recent advances in spaceborne X-band Synthetic Aperture Radar (X-SAR) technology have revived meteorological applications with this type of radar. At this wavelength, attenuation and backscatter caused by heavy precipitation and the melting layer within a storm can be, and have been, detected. Further investigation reveals polarimetric signatures that are in accordance with expected radar observations of storms. Based on real fully polarimetric S-band ground radar data from stratiform and convective storms, a model is constructed to simulate spaceborne X-SAR observations. The conversion between wavelengths and look angles is generated via scattering simulations of various hydrometeors described by a Drop Size Distribution (DSD) followed by regression analysis to determine a transform function. For small particles in the Rayleigh scattering regime, this is a simple curve fit, but Mie scattering is induced for large rain and hail causing oscillations in the received backscatter at X-band. In order to capture the relationship between polarimetric variables such as differential reflectivity, copolar phase shift and linear depolarization ratio for larger particles a neural network is used. Data from the CSU-CHILL S-band polarimetric radar are then applied to the model to simulate the propagation effects that might occur from a spaceborne X-SAR given the slant angle viewing geometry and 2-D imaging mode. Simulation results are compared to storm observations from several repeat pass dual-polarization TerraSAR-X acquisitions over Florida and ground-based horizontal polarization S-band weather radars.

7669-44, Session 9

Investigating directional structures in weather radar imagery

D. Charalampidis, The Univ. of New Orleans (United States)

Recently, efficient directional smoothing techniques were developed for filtering of weather imagery. In addition to being useful for visualization purposes, it was observed that directional smoothing filters could reveal directional structures that seemed to be associated with small-scale precipitation events. These small-scale events were usually embedded within larger-scale events. Although non-directional filtering was still capable of reducing noise and local variations, and thus assist in the identification of small-scale events, directional filtering seemed to be more capable of producing highly distinctive directional structures. Owing to the distinctiveness of the structures, it was observed that small-scale events could be analyzed further in order to determine their behavior. In this work, the temporal development of these structures is studied in order to identify the difference between small-scale event motion characteristics and that of the associated larger-scale event. An application in short-term forecasting is also investigated.

Short-term forecasting based on tracking of small-scale events is not a new concept. Recently, neural network techniques were developed for modeling weather imagery. A recent technique used Radial Basis Functions in order to model precipitation echoes as a combination of Gaussian envelopes. As opposed to tracking the large-scale precipitation events, the constituent envelopes were tracked. The difference between these approaches and the technique studied in this work is that the time consuming modeling processing is not required by the directional filter-based technique.

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7670-01, Session 1

A microwave imaging spectrometer for security applications

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In the last years the security of people and critical infrastructures is of increasing interest. Passive microwave sensors in the range of 1 100 GHz are suitable for the detection of concealed objects and wide-area surveillance through pure weather and at day and night time. The enhanced extraction of significant information about an observed object is enabled by the use of a spectral sensitive system. Like in optics the identification is often only feasible by colours. For a spectral radiometer also some depth information can be extracted. The usable frequency range is thereby dependent on the application. For through-wall imaging or detection of covert objects such as for example landmines, the lower microwave range is best suited. On the other hand a high spatial resolution requires higher frequencies or instruments with larger physical dimensions. The drawback of a large system is the required movement of a mirror or a deflecting plate in the case of a mechanical scanner system, or a huge amount of receivers in a fully-electronic instrument like a focal plane array. An innovative technique to overcome these problems is the application of aperture synthesis using a highly thinned array. The combination of spectral radiometric measurements within a wide frequency band, at a high resolution, and requiring a minimum of receivers and no moving parts led to the development of the ANSAS instrument. This system is a very flexible technology demonstrator for the analysis of main features and interactions of high spatial resolution together with spectral sensing within a wide frequency range of 1.4 GHz to 6.5 GHz. The system consists of a linear thinned array of fifteen broadband receivers, which delivers an optimum sampling up to the maximum baseline of 79 times the smallest antenna distance. In order to achieve a two-dimensional aperture the linear array is additionally rotated and thus the spatial frequency spectrum is measured on concentric circles. By this way the number of receivers and correlators is reduced considerably compared to a fully two-dimensional array, but measurements still can be done in a reasonable time. In this paper the basic idea of ANSAS is presented, the setup and receiver assembly is outlined, and some first imaging results showing basic capabilities are illustrated.

7670-02, Session 1

Passive millimeter-wave imaging and spectroscopy system for terrestrial remote sensing

N. Gopalsami, A. Heifetz, B. Taylor, A. C. Raptis, Argonne National Lab. (United States)

We have built a passive millimeter wave spectroscopy system with a 16-channel filter bank in the 146-154 GHz band. This talk will describe retrofitting of our spectroscopy system with an imaging element based on focal plane aperture coding. It uses a single pixel imaging system by sequentially coding the aperture of the focal plane with a set of NxN Hadamard masks where N is the number of pixels over the focal plane. Image acquisition is carried out by measuring the full field transmission through a sequence of N2 mask patterns of logical 0s and 1s. The Hadamard transform inversion is a simple matrix multiplication operation and mathematically provides a unique reconstruction of the NxN image. In conventional single pixel imaging in which either the lens (mirror) or the receiver element is scanned, the scanning system is generally cumbersome; or in the case of receiver scanning, it would also introduce cable noise. On the other hand, the aperture coding is possible with

no moving parts by electronically switching the mask patterns, and it can provide diffraction-limited image resolution by using large N and yet retaining high signal to noise ratio because nearly N/2 pixels are transparent in each mask. We will present theory and imaging results of this new approach.

7670-03, Session 1

Real-time passive terahertz imaging system for standoff concealed weapons imaging

A. R. Luukanen, MilliLab (Finland) and VTT Technical Research Ctr. of Finland (Finland); L. Grönberg, M. Grönholm, P. Lappalainen, M. Leivo, VTT Technical Research Ctr. of Finland (Finland); E. N. Grossman, C. R. Dietlein, National Institute of Standards and Technology (United States)

The performance stand-off imaging of concealed weapons in the mm-wave range remains limited by the relatively poor angular resolution using practical aperture sizes. For this reason, increasing the operating frequency of the systems is desired, but in practice is hard to realize due to the lack of affordable, low noise amplifiers well beyond 100 GHz. In this paper we present a passive terahertz imaging system which acquires passive terahertz (~200 GHz - ~1 THz) imagery near video frame rate. The system, one copy of which is built in Finland and the other in the U.S., is based on a 64 pixel linear array of superconducting antenna-coupled microbolometers operated within a commercial cryogen-free closed cycle cryocooler, and utilizes conical scanning Schmidt optics. Quantitative measurements on the imager resolution metrics (thermal, spatial and temporal) will be presented. The results from field tests at the Helsinki-Vantaa airport will be presented.

7670-04, Session 1

Progress report on Safe VISITOR: approaching a practical instrument for terahertz security screening

E. Heinz, G. Zieger, D. Born, A. Krüger, M. Schulz, T. May, S. Anders, V. Zakosarenko, H. Meyer, IPHT Jena (Germany); M. Starkloff, Supracon AG (Germany); M. Rößler, G. Thorwirth, U. Krause, Jena-Optronik GmbH (Germany)

As reported before, Safe VISITOR (Safe VISible, Infrared and Terahertz Object recognition) is a German project to build a passive security camera which visualizes sub-mm radiation using cooled bolometer arrays. This camera could be used for a variety of application scenarios, such as airport screenings or to protect military camps. In all cases, a practical instrument requires ease of use, in particular a flexible installation and a straight forward usage by the security personnel.

Here we present a new generation of Safe VISITOR designed to meet these requirements. The main condition for an effective operation is a high frame rate. Safe VISITOR is able to scan at up to 10 Hz, using a small array of superconducting bolometers in combination with an opto-mechanical scanner. The required cooling of the detector array is provided by a commercial pulse tube cooler with a second, self-contained cooling stage. The cooling cycle is completely automated providing continuous operation.

For imaging, a 50 cm diameter optics is used providing an object resolution of 1.5 to 2 cm from a object distance tunable between 7 and 10 m. Additionally, video streams from two commercial cameras are fused with the sub-mm stream: a CCD for visible light and a microbolometer for far infrared (14 μm). This combines the ability of

identifying the person under test with the unprecedented temperature resolution at infrared and the almost perfect transmission at sub-mm. To assist a security official, all image data are displayed in various graphic renditions by a unified system software.

7670-05, Session 1

First design investigations on a fully electronic microwave imaging radiometer

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Present applications of microwave remote sensing systems cover a large variety. One utilisation of this frequency range from 1 - 300 GHz is the domain of security and reconnaissance. Examples are for instance, the observation of sensitive areas or the performance of personal security checks in order to detect concealed weapons or explosives, both being frequent threats in our world of growing international terrorism. The imaging capability of concealed objects is one of the main advantages of microwave remote sensing, because of the penetration capability of electromagnetic waves through dielectric materials in this frequency domain. The main physical effect used in passive microwave sensing relies on the thermal radiation and the physical properties of matter, being surface characteristics, the chemical and physical composition, and the temperature of the material. So it is possible to discriminate objects having different material characteristics like ceramic weapons or plastic explosives with respect to the human body. Considering the use of a people scanning system in airports, railway stations, or stadiums, it is important that passive microwave imaging devices have no exposure on the scanned object like active devices do. For frequently used security gateways it is additionally important to have a high through-put rate in order to minimize the queue time. Consequently fast imaging systems are necessary. In this regard the conceptual idea of a fully-electronic microwave imaging radiometer system is introduced. The scanning mechanism for the two space dimensions is divided into a frequency scan in one direction and the method of aperture synthesis in the other. The overall goal here is to design a low-cost, fully-electronic imaging system with a frame rate of around one second at Ka band. This frequency domain offers a well balanced compromise between the achievable spatial resolution and the penetration depth of the electromagnetic wave, which are conflictive requirements.

7670-06, Session 1

Passive MMW polarimetric sensor

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The author presents a passive MMW pushbroom imager designed to accurately measure both H and V linear polarizations. The radiometer is designed to accurately measure radiometric temperature and degree of polarization, allowing the user to distinguish various materials in an aerial image. The imager uses a twin phased-array of W-band amplifiers to form a line imager with a 30-degree wide field of view. Polarizing optics in the reflector antenna path allow the twin arrays to have overlapping fields-of-view but to sense orthogonal linear polarizations. The radiometer is designed to produce images with sub-Kelvin temperature resolution when used at typical UAV speeds. The paper presents details of component development and performance. The paper also discusses further development which could make the system sensitive to S2 and S3 components of the Stokes vector.

7670-07, Session 2

Standoff concealed weapon detection using a 350-GHz radar imaging system

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The sub-millimeter (sub-mm) wave frequency band from 300 - 1000 GHz is currently being developed for standoff concealed weapon detection imaging applications. This frequency band is of interest due to the unique combination of high resolution and clothing penetration. The Pacific Northwest National Laboratory (PNNL) is currently developing a 350 GHz, active, wideband, three-dimensional, radar imaging system to evaluate the feasibility of active sub-mm imaging for standoff detection. Standoff concealed weapon and explosive detection is a pressing national and international need for both civilian and military security, as it may allow screening at safer distances than portal screening techniques. PNNL has developed a prototype active wideband 350 GHz radar imaging system based on a wideband, heterodyne, frequency-multiplier-based transceiver system coupled to a quasi-optical focusing system and high-speed rotating conical scanner. This prototype system operates at ranges up to 10+ meters, and can acquire an image in 10 - 20 seconds, which is fast enough to scan cooperative personnel for concealed weapons. The wideband operation of this system provides accurate ranging information, and the images obtained are fully three-dimensional. During the past year, several improvements to the system have been designed and implemented, including increased imaging speed using improved balancing techniques, wider bandwidth, and improved image processing techniques. In this paper, the imaging system is described in detail and numerous imaging results are presented.

7670-08, Session 2

Efforts toward an interferometric passive mmW imager for helicopter brownout mitigation

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The capability of millimeter-wave energy for penetrating typical atmospheric obscurants is well known and viable imagers in this regime could provide potential benefits for many applications. One such application is to mitigate the impacts of brownout conditions commonly experienced by helicopter pilots when landing or transferring cargo in dusty or sandy conditions. The severity of these conditions is highly dependent on the type of airframe as well as the condition of the landing area. Herein, the design of an interferometric, passive imager tailored to brownout mitigation will be presented. The specific considerations for solutions to brownout mitigation, particularly on larger rotorcraft frames, will be discussed. Experimental measurement of the relative impact of "worst-case" dust clouds generated by a range of rotorcraft will be shown. This data is based on field measurements of the radiometric attenuation induced by actual rotorcraft-generated brownout conditions.

7670-09, Session 2

Indirect holographic imaging: evaluation of image quality at 310 GHz

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We present an active THz-imaging technique, which utilizes holographic process in image retrieval. In this technique, information of the target is stored in an interference pattern. The pattern is formed with a reference beam and that of reflected from the target. This technique, called indirect holographic imaging, involves only amplitude detection. In this method, image retrieval is a two-staged process: first the complex field reflected from the target is calculated from the interference pattern, and then the

field is back propagated to the distance for the target. The complex form of the reference beam must be known. Both stages of the computation are based on Fast Fourier Transform. Cross-range resolution of 0.1° is achieved with an experimental imager at 310 GHz with 40-cm virtual aperture. The imager consists of standard millimeter-wave antenna near-field measurement range in which a single receiver is scanned across the rectangular aperture area. A single transmitter with a directional coupler and corrugated horn antennas is used both in illuminating the target and creating the reference beam. Requirement to measure the phase distribution of the reference beam is avoided by adding a calculated spherical phase front corresponding to the setup geometry. The imager performance is described with dynamic range and number of levels of the image brightness, as well as with the cross-range resolution and depth of focus. The performance of the 310-GHz imager is assessed with variable reference-beam approaches, system signal-to-noise ratios, and sampling intervals.

7670-10, Session 2

Millimeter-wave compressive holography

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This paper describes an active millimeter-wave (MMW) holographic imaging system for concealed weapons detection. We record a digitized on-axis, Gabor hologram using a single pixel incoherent receiver that is translated at the detector plane to form a composite image. Capturing measurements in the MMW regime is costly since scanning systems can be plagued by their long data acquisition times. Thus, we leverage recent advances in compressive sensing with a traditional holographic method in order to estimate a 3D (x,y,z) object distribution from a 2D recorded hologram. The 3D image is estimated by minimization of a convex quadratic function using total variation (TV) constraints. We demonstrate this approach by imagining semi-transparent objects that mimic weapons and other objects. We present 3D reconstructions of objects at various depths estimated from a 2D recorded hologram. We compare backpropagation results with our decompressive inference algorithm. A possible application includes remote concealed weapons detection at security checkpoints.

7670-11, Session 2

Millimeter-wave measuring system for biomedical applications

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This paper reports results of the research work on development of techniques and devices for measuring of extra low radiation in mm-range. This radiation is widely used for investigation of environment and medical diagnostics of human physiological state. There are considered basic engineering aspects of measuring extra low mm-range radiation in the paper. It is also described an original measurer that helps researchers to get more clear understanding about environment physics and biomedical physiology, how low energy mm-range radiation interacts with human organism. Certain applications have been proposed for the measurer as for testing calibrating and diagnostic devices. This paper should be considered as a current completed step in the research process of a role of extra low mm-range radiation on environment and human being as well. At this step a previous mm-range extra low radiation measuring and medical experience had been analytically summarized. This analysis made possible to accept an assumption how we are able to measure (investigate) mm-wave influence on objects and human organism as well. It should be noticed that only extra low radiation was taking into account. There was the main problem, that it was required to measure radiation at the noise level. That is why the main task had been decided how these measurements must be provided. An original measurer was

developed for investigations above mentioned. Proposed measuring system consists of subsystem of reflected or/and self radiation scanning and subsystem of hardware-software processing scanned data from the object.

7670-12, Session 2

Performance limitations of compressive sensing for passive millimeter-wave imaging

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This paper describes inherent performance limitations for compressive sensing schemes that utilize a single detector. We show that diffraction fundamentally limits the detection efficiency of single-detector imaging schemes and degrades image quality. We quantify noise performance of compressive sensing using a publicly available CS algorithm and compare CS performance to that of staring and raster scanned approaches. The results suggest that the performance of single detector CS imagers is inferior to both staring and raster scanned techniques.

7670-13, Session 3

Development and testing of millimeter-wave simulants of explosives at the Transportation Security Laboratory

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With the advancement of millimeter wave (MMW) imaging for explosives detection, it is necessary to develop inert materials that respond similar to explosives for safe and effective evaluation of security devices. Also, the development of models for the scattering of MMW for detection of suicide bombers requires measurement of the dielectric constant of explosives. The Transportation Security Laboratory (TSL) has developed a first generation of MMW simulants for several explosives using inert materials. Experimental techniques have been developed in order to standardize measurement results. Results of permittivity measurements and a comparison of the anticipated signal returns are presented for the range 75 - 475 GHz.

7670-14, Session 3

Emission from dielectric materials in millimeter wavelengths in passive thermal environments

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Imaging in millimeter and sub-millimeter wavelengths is a method applied in personnel screening systems to detect concealed explosives. The appearance of objects on a person detected in millimeter waves is governed by the reflectivity, absorptivity, and emissivity of the constituent materials; these attributes are connected to physical optical properties and temperatures. In this paper, the brightness of radiation escaping a two-dimensional slab of material under ambient illumination is characterized in terms of its complex dielectric constant. Transmission and reflection coefficients are derived from wave optics and the application of Beer's law, and the emissivity follows from detailed balancing. The solutions are compared with intensities measured with millimeter-wave imaging systems. In addition to a framework for modeling images according to the electromagnetic parameters of constituent materials, the model also suggests a method to detect the

complex dielectric constant at millimeter-wave frequencies.

7670-15, Session 3

Body-borne IED detection: NATO DAT#10 BELCOAST 09 demonstration results

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Belgium leads the tenth initiative in the CNAD Programme of Work for the Defense Against Terrorism (PoW DAT), dealing with Critical Infrastructure Protection (CIP). The BELCOAST 09 event, comprising a series of technology demonstrations, was organized to tackle the need for an event that brings together the operational, armaments and technological communities in the field of CIP. A counter terrorism scenario has been created: Terrorist with body-borne IED approaching the entrance of an installation, and a millimeter-wave imager's ability to detect IEDs has been demonstrated. The results of this scenario-based demonstration are presented in this paper.

7670-16, Session 3

Image registration and fusion of millimeter-wave and visual images for concealed object detection

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This paper addresses the registration and the fusion techniques between passive millimeter wave and visual images for concealed object detection. The passive millimeter wave imaging (PMMW) system detects concealed objects such as metal and man-made objects as well as water and small liquid and gel containers. A visual imaging sensor records detailed figures of a person under security but not concealed objects under clothing. In this work, we propose automatic registration and fusion methods between the MMW and visual images. The registration process is composed of feature extraction and matching stages. Body areas in two images are adjusted in scale, location, and orientation to fit to each other. After the registration process, the image fusion combines meaningful information from them. The image fusion method is based on discrete wavelet transform and a fusion rule, which adaptively emphasizes the different information and combines them in one fused image. The experimental and simulation results show the proposed technique can detect a concealed object and fuse two different types of images in a fully automated way.

7670-17, Session 3

A millimeter-wave technique for standoff detection of concealed knives and weapons using multiple polarisation interrogation

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The effective covert detection of concealed knives and other metal weapons at stand-off distances is an important challenge for security personnel and requires techniques beyond conventional portal and passive microwave imaging methods. A novel active ultra wideband millimetre wave technique has been developed which uses two linearly polarised transmitter horns with polarisation orientated at 45 degrees to each other, and two detector horns, which are inclined at right angles to the two transmitters. By measuring and combining signals from the four detector/transmitter combinations, the radar return from elongated metal objects, such as concealed knives can be detected and distinguished

the stronger return from the human being target, regardless of the orientation of the knife. A data analysis method using artificial neural networks has been successfully implemented, which enables knife-like objects to be distinguished from commonly carried benign objects, such as phones and cameras. The development of a system capable of practical deployment is described. Finite element simulations have been used to show how the return signal from a range of modelled objects varies with polarisation. The behaviour varies considerably from when the wavelength is comparable with the size of the object to when it is much smaller. However, a characteristic polarisation signature is present throughout and this enables the technique to be used at millimetre wavelengths where quasi-optic techniques can be used for detection at stand-off distances.

7670-18, Session 3

Active THz inspection of water content in plants

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Imaging in the THz range opens up new possibilities in quality control processes in the industry. In this case we will implement an imaging system to measure the water content of a plant by THz inspection of the leaves.

The objective arises from the wine industry with the aim of reducing costs for irrigation accurately measuring of the water content of the plant, therefore.

The initial imaging system used is based on active images in transmission, which are attenuated to a greater or lesser extent depending on the water content of the plant. The measurement system is based on a network analyzer as a source and does not use optical parts (not focused the beam), but to measure the water content of the sample.

In view of the results, significant differences in the areas of higher water content (nerves) versus those which are gradually drying (edges of the leaf) can be seen. Even without the use of lenses, the edge of the leaf, some of the peaks and the knot of nerves can be clearly distinguished

The next step will be to include optics to focus the beam and to improve the resolution and differentiate the nerves of the leaf, as well as holes or tears.

7670-19, Session 4

Development of small form factor 94-GHz imaging receivers using new semiconductor and packaging technologies

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94GHz remains the most suitable band for high resolution near-real-time imaging in defence and security applications. The optical benefits of high frequencies are countered by reduced penetration and by very high component costs. Low cost semiconductor processes with low noise and high gain in the W-band are now becoming available, and low cost packaging is increasing being used for 94GHz components

Gallium Arsenide GaAs semiconductors have lacked high gain in the W-band, so their use in imaging has required multiple amplifier stages resulting in higher cost. Indium Phosphide semiconductors conventionally offer higher gain at 94GHz, but are not widely available at low cost and are very fragile in manufacturing. New metamorphic HEMT GaAs processes with gate lengths under 100nm are now available with higher gain and at low cost. This paper reviews the considerations in selecting processes to design amplifiers for W-band imaging, and describes the design of a multiple-stage amplifier device with gain >30dB in the W-band.

New multi-layer substrate technologies using Liquid Crystal Polymer

offer low loss at W-band (e.g. stripline waveguides at <0.04dB/mm) and very compact placement of high frequency and other components. These circuit boards also allow for low cost, high volume, automated manufacturing of both surface mount components and wire-bonded or flip-chip semiconductor devices. This paper describes the design and measurement of 94GHz direct detection receivers based on multi-layer LCP substrates to achieve a very small form factor, a volume of 0.8cm3, which supports integration into tightly packed 1D and 2D arrays.

7670-20, Session 4

A sub-millimeter-wave line imaging device

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In this paper we present a single mode active device for sub-millimeter wave line imaging. The illuminated scene is imaged through focusing optics onto a device we have been developing and have dubbed a spatially selective mirror (SSM). This device reflects parts of the image onto a heterodyne receiver. Currently the SSM is capable of reflecting user-selectable parts of one line of the image that is focused on it. Multiple patterns are used to sample a line in the image. The voltage in the receiver resulting from each pattern constitutes an independent measurement of the illuminated scene along a line. A one dimensional image is reconstructed from the measurement results and a priori knowledge of the patterns using methods derived from the theory of compressive sensing. The theory behind the device and the design principles we use are reviewed. The methods and materials used to construct the device used in this study are presented. We show and compare line images obtained at both 340 GHz and 640 GHz. Extension of this technique to two dimensional imaging is discussed.

7670-21, Session 4

An 850-micron high-resolution high-sensitivity passive video imaging system

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Millimeter wavelength radiation holds promise for identification of security threats at a distance, such as identifying suicide bomb belts. The sensitivity provided by superconducting Transition-Edge-Sensor (TES) bolometers makes them ideal for high sensitivity passive imaging of thermal signals at millimeter and submillimeter wavelengths. We are

developing an 850 um video-imaging system using TES bolometers as detectors. This demonstration system will image a 1 m x 1 m target at a distance of 16 m to a resolution of approximately 1 cm. Video images with noise-equivalent temperature difference of 50 mK will be generated at 10 frames per second. Light is captured by an f/2.0 Cassegrain optical system with 1.3 m primary mirror. In the initial demonstration system, the focal plane consists of 800 TES bolometers cooled to .8K. The pixels will initially be read out using a time-domain multiplexed

SQUID readout system. We will describe current progress on development of this system.

7670-22, Session 4

A fully integrated W-band passive imaging receiver IC in silicon-germanium BiCMOS technology

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Advanced silicon technologies can potentially reduce the cost of PMMW imagers owing to their high integration capability and economies of scale. This paper presents the first single-chip silicon-based W-band direct-detection imaging receiver suitable for focal plane arrays. The IC consists of an LNA, a detector, baseband circuitry and Dicke-switch functionality, on a 5mmX2.5mm die. The receiver chip has been fabricated in a commercial silicon-germanium (SiGe) BiCMOS technology, offering 0.15-µm HBTs with 200-GHz fT/fmax. On-wafer measurements have been performed on the receiver IC. The receiver achieves an average responsivity of 40,000 kV/W in the W-band. A balanced switching LNA topology with 31-dB peak gain enables a receiver noise figure of 11 dB and a minimum temperature resolution (NETD) of 0.3 K with 30-ms integration time. The measured responsivity and noise figure of the detector circuit are 90 kV/W and 28 dB, respectively. The imager chip consumes 225 mW from a 1.8-V supply.

Architectural, circuit-level and device-level challenges specific to silicon-based implementations of PMMW receivers are discussed. Low-frequency noise performance of silicon transistors is presented along with the analysis of NEP and responsivity of silicon-based detectors.

7670-23, Session 4

Orotron-based sub-millimeter-wave source

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We describe progress towards a handheld Orotron sub-mm-wave source with the ability to scan through a range of frequencies around 500 GHz. The Orotron is in the same family of electron-beam devices as traveling wave tubes (TWTs) and Klystrons, but has a geometry more suited to this frequency range. We discuss the trade-offs in device design that led us to a sheet-beam geometry, a carbon-nanotube field-emission electron gun, permanent magnets for beam confinement, and result in small total device size. Applications include a source for sub-mm-wave and THz imaging and spectroscopy at ranges of up to 10 m. Compared to TWTs operating at lower frequencies, in our device the generation and confinement of the beam is more straightforward, the MEMS fabrication techniques easily meet the required tolerances, but the alignment of the beam with the physical structures is far more challenging. The Smith-Purcell grating in the cavity is 1 cm x 3 cm, and is fabricated by LIGA. The CNT electron gun can supply a sheet beam, without any electron optics, of the correct dimensions and at sufficient current density (0.3 A/sq. cm) to turn on the device. The CNTs are grown on a 1 cm square die and emit directly a sheet-beam of dimensions 8 mm by 5 microns. The electron gun is a 1.6 mm stack consisting of the CNT die, Si extraction electrode, and Si acceleration electrode. The device package, excluding magnet, is likely to be 6 cm x 2 cm x 1 cm.

7670-24, Poster Session

Control system for millimeter-wave medical diagnostics

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This paper reports results of the research work on development of control system for millimeter-wave medical diagnostics. In particular there are considered control subsystem as a part of millimeter-wave diagnostic system. Millimeter-wave diagnostic system consists of control subsystem, scanning subsystem and measuring subsystem. It has been investigated a possibility to improve a scanning process and a measuring process by the control subsystem for higher effective millimeter-wave medical diagnostics. Control subsystem operates managing over scanning and measuring process by means control and check signal for measurer switching, scanning start and stop, receive and transmit a data from millimeter-wave sensor, table manipulation. There were investigated main operations of scanner subsystem: orientations of table with object, forming positioning control impulses, start and stop operation of the scanning subsystem. Second, there were investigated following main operations of the measuring subsystem: receiving a radiation from biological object by the detector unit, start and stop operation of the detector units, forming a signal of start and stop operation of the detector unit, transmitting data to the data processing unit. The detector unit registers radiation from biological object or/and test generator. There is used a synchronizer for correct work of scanner subsystem with measuring subsystem. For example, the detector control impulses should be synchronized with the positioning control impulses. If the detector control impulses are longer than the positioning control impulses, it causes the incorrect imaging. Investigation of the synchronizing algorithms has proved ability of control system to improve the efficiency of millimeter-wave medical diagnostics system.

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7671-01, Session 1

Plasmon-resonant microchip emitters and detectors for terahertz sensing and spectroscopic applications

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In the research of modern THz electronics, development of compact, tunable and coherent sources/detectors operating at THz frequencies is one of the hottest issues. Two-dimensional (2D) plasmons in semiconductor devices like a HEMT have attracted much attention due to their nature of promoting emission/detection of electromagnetic radiation in the THz range. This paper reviews recent advances in emission/detection of terahertz (THz) radiation utilizing two-dimensional plasmons in semiconductor heterostructures and their possible sensing and spectroscopic applications. We have developed our original plasmon-resonant double-grating-gates high-electron mobility transistors utilizing GaAs-based or InP-based heterostructure material systems. The device features an interdigitated dual-grating gate structure that periodically distributes the plasmon resonators over the channel and acts as a broadband antenna converting non-resonant plasma waves to radiative THz electromagnetic waves. In terms of THz emitters experiments revealed the performances exhibiting 1- W, broadband (0.5-to-6.5-THz) emission at room temperature. The device was introduced as a light source into a Fourier-transform THz spectrometer. Water-vapor absorption lines as well as fingerprints of honey and maple syrup of suger-group materials were successfully observed. In terms of THz detectors it revealed a broadband (0.5-to-6.5-THz) detection with an excellent responsivity at room temperature. The device can work for an active THz imaging systems as a THz sensor chip. Further improvement on emissivity, sensitivity, directivity, and coherency of THz radiation will also be addressed from the view point of heterostructure materials, metamaterial antennae, and optical injection locking.

7671-02, Session 1

Aging and embedding issues for high-Tc superconducting hot-electron bolometers for THz imaging

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Superconducting Hot Electron Bolometer (HEB) mixers are a competitive alternative to conventional superconducting technologies in the terahertz frequency range because of their ultrawide bandwidth (from millimeter waves to the visible), high conversion gain, and low intrinsic noise level, even at 77 K. A technological process to fabricate stacked YBaCuO / PrBaCuO ultra-thin films (in the 15 to 40 nm thickness range) etched to form 0.4x0.4 sq-micrometer constrictions, elaborated on MgO (100) substrates, has been previously described. Electronic and UV lithography steps were combined to realize HEB mixers based on such structures covered by a log-periodic planar gold antenna, aiming at covering the 0.9 to 7 THz range. Ageing effects were also observed, with the consequence of increased electrical resistance, significant degradation of the regular bolometric response, preventing HEB mixing action as well. Several measures have been attempted to address these problems, mainly by considering the embedding technological issues related to the YBaCuO nanobridge coupling to the antenna and the

intermediate frequency (IF) circuitry. For this purpose, the nanobridge impedance was analyzed, and mismatch to antenna and IF strip were considered. In particular, extensive antenna simulations were performed and validated against experiments on scaled models at GHz frequencies. Electromagnetic coupling to the incoming radiation was also studied with these models, including crosstalk between neighbor antennas forming a linear imaging array. Finally, optical solutions to address local oscillator power distribution among array elements was also considered.

7671-03, Session 1

Terahertz detection with field-effect-transistors via bulk plasmon-assisted self-mixing

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We have previously reported on sensitive terahertz detection with bulk plasmons in GaAs field-effect-transistors (FETs) and introduced a phenomenological, qualitative theory to explain the experimental observations [1]. The initial theory could explain the observed voltage- and frequency-dependent resonance features with an assumption of bulk plasmon excitations at two space-charge regions in the FET. However, the theory was incomplete, lacking explanation of the photovoltaic nature of the detector responses. Recently, U.R. Pfeiffer et al. [2] and Lisauskas et al. [3] reported terahertz detection with Silicon FETs and introduced an electronic circuit model of terahertz self-mixing for the photovoltaic signal generation. These works also elucidate the connection between their self-mixing theory and the Dyakonov-Shur 2D plasma-wave theory [4]. Here we introduce a similar device model which incorporates the microscopic dynamics of terahertz-field-driven electrons in the FET channel, resonant excitation of three dimensional (bulk) plasmons, and the self-mixing theory. The resulting new analytical model complements our previous work and brings an interpretation of bulk plasmon-assisted terahertz self-mixing to the FET-based terahertz detectors. The model also suggests three important factors to improve the performance of this type of devices - power coupling efficiency, self-mixing efficiency, and resonance with bulk plasmons.

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7671-04, Session 1

Radiometer-on-a-chip: a path toward super-compact sub-mm imaging arrays

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Active THz imaging with coherent heterodyne systems has shown great promise towards achieving 'see-through' capability at standoff distances approaching several 10s of meters. A 600 GHz system utilizing a 1 m

aperture will have a diffraction-limited resolution of 2 cm for a standoff distance of 50 m. This resolution is sufficient for several threat scenarios. Most of the work done so far has been with a single pixel approach. Recently, we have developed and demonstrated a twin-pixel approach that significantly enhances performance metrics, most notably image capture speed, an extremely important criterion for any practical system. However, extending the approach towards a large pixel system based on the current state of submm components is not practical or even feasible. We present an approach that utilizes silicon micro-machining along with advanced wafer-bonding techniques to fabricate complete radiometers on a stack of semiconductor wafers. The individual semiconductor wafers in the stack allow one to optimize and select the most appropriate technology for each functionality necessary for heterodyne detection. The basic concept along with preliminary results and designs from 100 to 600 GHz will be presented. This technique allows one to package GaAs Schottky diodes, InP based power amplifier MMICs, and novel planar antennas all in a stack of wafers enabling a low-mass extremely compact radiometer front-end. This approach allows for the development of a super-compact submm imager that can readily be deployed.

7671-05, Session 1

Reconfigurable metamaterials for broadband terahertz modulation

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Existing modulator designs in the optical and infrared regime which use Fabry-Perot filters, liquid crystals, magneto-optic effects, quantum well structures, or deformable mirrors, do not operate efficiently at terahertz frequencies because of the lack of materials with the desired properties at terahertz frequencies and/or the practical difficulties in scaling the device dimensions to efficiently operate at terahertz frequencies. On the other hand, metamaterials are promising candidates for realizing terahertz modulators. This is because their spectral response can be engineered by their geometry, rather than being limited by characteristics of the existing materials at terahertz frequencies. The use of metamaterials has been previously demonstrated for realizing narrowband terahertz band-pass filters and modulators.

In this work, we present a terahertz modulation scheme based on reconfigurable metamaterials, which offers higher modulation depth and higher modulation bandwidth compared to the state-of-the art. The superior performance of the presented terahertz modulator is due to the use of subwavelength metallic slits which allows close to 100% transmission of an incident TM-polarized wave over a broad range of frequencies. The initial theoretical and experimental results promise feasibility of a terahertz modulation depth of more than 4.5 over a broad modulation bandwidth of 2THz. Such terahertz modulators will significantly improve the image contrast and sensitivity of single-pixel terahertz imaging systems which use broadband terahertz sources and are based on compressive sensing.

7671-06, Session 1

GaN-based THz quantum cascade lasers

T. Manzur, Naval Undersea Warfare Ctr. (United States); M. Anwar, Univ. of Connecticut (United States); E. M. Carapezza, Defense Advanced Research Projects Agency (United States)

GaN-based pseudomorphic heterostructures with their demonstrated superior thermal performance suggest an alternative to the standard GaAs-based technology to realize high power lasing at THz frequencies. In this talk, we will discuss the required design methodologies for the fabrication of a successful GaN-THz laser. The theoretical calculations will include among other parameters; (a) applied bias induced stress related bandgap and band-offset, (b) self-consistent solution of Schrödinger and Poisson's equations under the framework of a complete electro-mechanical model and (b) carrier dynamics in quantum confined system in the presence of longitudinal phonons.

7671-07, Session 1

Mid-IR optical fiber development for transport and super-continuum applications

A. Chavez-Pirson, W. Shi, NP Photonics, Inc. (United States)

We will describe our early development efforts in the fabrication of low loss optical fibers based on tellurite and germanate glasses for demanding applications requiring high power transport of single mode beams in the Mid IR (2μm-5μm) as well as all fiber-based super-continuum approaches to generate high power, single mode beams with extremely wide (1μm-5μm) and simultaneous wavelength coverage. As part of this activity, we have developed asymmetric fusion splice techniques for reliably joining the relatively low Tg glass fibers to conventional silica fibers. We will describe our experimental results to date.

7671-08, Session 1

Optimization of semi-insulating surface-plasmon waveguides within terahertz QCL's using computational models

C. Baird, B. Crompton, P. Slingerland, R. Giles, Univ. of Massachusetts Lowell (United States); W. E. Nixon, U.S. Army National Ground Intelligence Ctr. (United States)

The possibility of a compact source of coherent terahertz radiation is being realized through the development of quantum cascade lasers (QCL's). These lasers consist of a semiconducting heterostructure active region and an internal waveguide that make intraband lasing transitions possible. The use of terahertz QCL's in promising applications such as medical imaging, defense, and security is currently limited by low output laser power. Systematic optimization of the QCL's waveguide reduces mode losses, improves confinement, and increases output power. Waveguide optimization is especially important for lasers operating at low terahertz frequencies where semi-insulating surface-plasmon waveguide performance degrades significantly. Prediction codes have been developed that systematically optimize semi-insulating surface-plasmon waveguides. The methods and results of these optimizations will be presented for a full suite of terahertz QCL waveguides at different frequencies. The use of the optimization code to investigate graded-doping waveguide structures will also be presented.

7671-09, Session 2

Terahertz absorption spectra of highly energetic chemicals

E. J. Slingerland, M. Vallon, E. G. E. Jahngen, R. H. Giles, T. M. Goyette, Univ. of Massachusetts Lowell (United States)

Research into absorption spectra is useful in the pursuit of detecting chemicals in the field. Each molecule absorbs a set of specific frequencies, which are dependent on the molecule's structure. While theoretical models are available for predicting the absorption frequencies of a particular molecule, experimental measurements are a more reliable method of determining a molecule's actual absorption behavior. The goal of this research is to explore chemical markers (absorption frequencies) that can be used to identify molecules of interest to the remote sensing community. In order to increase the usefulness of the data gathered, particular attention was paid to the frequency ranges located within the terahertz transmission windows of the atmosphere. In addition, theoretical derivations, with the purpose of calculating the detection limits of such chemicals, will also be presented.

7671-10, Session 2

Identification of hazardous substances using terahertz spectroscopy

J. Jonuscheit, M. Herrmann, M. Theuer, S. Wohnsiedler, C. Wiegand, G. Torosyan, R. Beigang, Fraunhofer-Institut für Physikalische Messtechnik (Germany)

Terahertz (THz) spectroscopy is a promising technique for the identification of hidden objects. The THz band is particularly well suited firstly because THz radiation penetrates many dielectrics like clothing and secondly because many potentially hazardous substances have characteristic signatures in the THz spectral region. In order to demonstrate the full potential of THz radiation for identifying possible hazards using characteristic signatures, different disturbing influences must be taken into account.

We have performed experiments and simulations in order to investigate the possibilities and the challenges of terahertz identification. Special emphasis is paid on transparency of clothing and properties of the sample like surface roughness and orientation with respect to the incident THz beam.

In most realistic cases substances to be identified in security applications are hidden behind clothing or stored within containers. The transmission characteristics of these materials have a strong influence on the spectra. Therefore we have investigated different clothing and packaging materials.

The surface roughness of the sample modifies and limits the bandwidth of the reflected spectra. Specular and diffuse reflection measurements using samples with different roughnesses have been used to determine the influences of different properties on the reflection spectra.

7671-11, Session 2

Low THz spectroscopy of some widely used explosives

T. Globus, B. L. Gelmont, T. Khromova, Univ. of Virginia (United States)

We investigated resonance spectroscopic features from several widely used explosives materials including RDX and PETN in the low THz range with the goal of understanding the mechanism of interaction between radiation and material in the form of solid films, gels and dilute solutions (suspensions). Fourier transform spectroscopy was used in this study to measure spectra in transmission and reflection modes. We demonstrated that very small amount of material and a simple preparation technique of samples can be used still providing very accurate results. Spectral features are specific not only for main ingredients but for modifications with different plasticizers. The consistency of results for different amount of material was observed. Computational modeling confirmed the lowest frequency modes. One of the key question to answer was the relation between intermolecular mechanism and environment around molecules. The closely related question was the importance of material crystalline structure. The understanding of these issues is important for a practical application of THz spectroscopy for detection of explosives.

7671-12, Session 2

Continuous-wave THz emitter arrays for spectroscopy and imaging applications

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We report on arrays of n-i-pn-i-p-superlattice photomixers for potentially highest optical to THz efficiency. The output power of a single emitter has been improved recently to nearly 1 µW around 1 THz without any limitations for further enhancement. Tunable CW THz-sources for imaging and spectroscopy are highly desired tools for security and environmental applications. In particular, most stand-off imaging applications require a high THz power to allow for a high dynamic range as well as a narrow illuminating spot for high spatial resolution. Both goals can be reached by using an array of mutually coherent photomixers. We have simulated [1] beam patterns for an arbitrary number of mutually coherent single sources with respect to small beam sizes and high peak intensity. We confirmed the simulations experimentally by an array of 4 sources with 4 inch THz beam optics. The beam profile is measured in the target plane at a stand-off distance of 4.2 m. As a result, the beam diameter is reduced by a factor of 6 and the intensity is enhanced by a factor of close to $(4)^2 = 16$, in excellent agreement with our simulations. Such an arrangement allows not only for high resolution stand-off imaging but also for spectroscopic investigations at stand-off distances as the spectral linewidth of the sources is only determined by the mixing lasers and can be extremely narrow. We have performed water vapour spectroscopy in laboratory air with a single source as a preliminary test.

[1] S. Preu et al., Proc. SPIE 7117, 71170S (2008)

7671-13, Session 2

Effect of periodic roughness and surface defects on the terahertz backscattering behavior of cylindrical objects

A. Jagannathan, A. J. Gatesman, T. M. Horgan, T. M. Goyette, M. J. Coulombe, R. H. Giles, Univ. of Massachusetts Lowell (United States); W. E. Nixon, U.S. Army National Ground Intelligence Ctr. (United States)

This paper discusses the effect of periodic roughness and surface defects on the electromagnetic scattering of terahertz waves from cylindrical objects. The cylinders, possessing periodic roughness imparted during their fabrication process, were polished to various levels creating root mean square roughness values ranging from 0.1 µm - 1.5 µm. Metallic cylinders were fabricated from lathe-turned aluminum rods and dielectric cylinders were fabricated using stereolithographic techniques. The backscattering behavior of the rough cylinders was measured at 160 GHz, 350 GHz, and 1.56 THz in order to analyze the frequency dependence of the scattering behavior. In addition, the effect of seams and gaps on the scattering behavior of cylinders will also be presented.

7671-14, Session 2

Infrared/terahertz double resonance for chemical remote sensing: signatures and performance predictions

D. J. Phillips, E. A. Tanner, Digital Fusion Inc. (United States); H. O. Everitt, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States); I. R. Medvedev, C. F. Neese, J. Holt, F. C. De Lucia, The Ohio State Univ. (United States)

Single resonance chemical remote sensing, such as Fourier-transform infrared spectroscopy, has limited recognition specificity because of atmospheric pressure broadening. Active interrogation techniques promise much greater chemical recognition that can overcome the limits imposed by atmospheric pressure broadening. Here we introduce infrared - terahertz (IR/THz) double resonance spectroscopy as an active means of chemical remote sensing that retains recognition specificity through rare, molecule-unique coincidences between IR molecular absorption and a line-tunable CO_2 excitation laser. The laser-induced double resonance is observed as a modulated THz spectrum monitored by a THz transceiver. As an example, our analysis indicates that a 1 ppm cloud of CH_3F 100 m thick can be detected at distances up to 1 km using this technique.

7671-15, Session 2

Periodic extension for implementation of wavelet methods in terahertz reflection spectroscopy

M. H. H. Arbab, D. P. Winebrenner, A. Chen, E. I. Thorsos, Univ. of Washington (United States)

In this paper, we show different implementations of wavelet methods that can successfully retrieve terahertz spectroscopic information from rough surface targets. In previous works, we have demonstrated that when terahertz waves are scattered by surface roughness, the effects of scattering can obscure stand-off detection of chemicals using terahertz time-domain spectroscopy [1-2], particularly in the reflection mode [3]. By means of theoretical electromagnetic scattering simulations, we have shown that this phenomenon primarily occurs when material grain sizes and/or their RMS surface roughness heights are comparable to the wavelength of the terahertz radiation. In other work, we have demonstrated that commonly used frequency-domain deconvolution methods fail to accurately detect and characterize the resonance in the dielectric constant of rough surface lactose samples [3]. However, wavelet transforms can be used to consistently detect such features in almost every lactose sample[4]. Still, due to an exponential decline of terahertz bandwidth, in the presence of such scatterings, implementation of discrete wavelet transforms requires careful mathematical treatment and detrending of the reflected signal prior to the application of wavelet methods. To address this issue, several numerical techniques are presented including a periodic extension for treatment of the circular boundary condition problem of wavelet methods.

1. L. M. Zurk et al., "Electromagnetic scattering calculations for terahertz sensing," Proc. SPIE 6472 (2007).

2. L. M. Zurk et al., "Terahertz scattering from granular material," J. Opt. Soc. Am. B 24, 2238-2243 (2007)

3. M. Hassan Arbab et al., "Effect of surface scattering on terahertz time domain spectroscopy of chemicals," Proc. SPIE 6893(1), p. 68930C, 2008.

4. M. Hassan Arbab et al., to appear in Proc. of SPIE Photonics West 2010.

7671-16, Session 2

Method of THz spectrum dynamics analysis for identification of compound medium

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For defense and security problems as well as for quality control and pharmaceutical industries it is very important to get reliable information about compound media which may contain dangerous chemical and biological substances, explosives, dirt, etc. We propose to use the method of THz spectrum dynamics analysis (SDA-method) for identification of such media and detection of dangerous components. The algorithm of identification is based, for example, on the SVD-method (method of Singular Value Decomposition) for reconstruction of the signal by the set of its integral values and sliding window method for obtaining the THz and GHz spectrogram - dynamics of its Fourier spectrum. It allows to follow the dynamics of many spectral lines in one set of measurements simultaneously and to obtain the full information about the spectrum dynamics of the signal even measurements are made over a short time interval (less than 20 ps).

If measurements are made over a long (about 100 ps) time interval, relaxation time for excited energy levels of molecules may be determined from the spectrogram too. As molecules of various materials have at least a part of non-coinciding intermode transitions, this fact can provide another basis for substances identification.

In order to demonstrate a possibility of SDA-method we consider the

examples imitating the real case of explosives mixed with harmless substances in different ratio - as a sum of two signals, passed through neutral material and explosive. Our investigations show that that THz and GHz spectrograms of the sum of THz pulses widely differ from spectrograms of neutral pulses and it is possible to detect the presence of additional substance in the neutral material even if the amplitude of the additional part of the signal is ten times less than the amplitude of the neutral part.

Therefore, the method allows detecting and identifying additional substances in compound media with high probability and can be very effective for different applications including defense and security.

7671-17, Session 3

Guided-wave terahertz characterization of fingerprint lines in threat materials

J. S. Melinger, U.S. Naval Research Lab. (United States); D. R. Grischkowsky, Oklahoma State Univ. (United States)

An important application of terahertz spectroscopy is the measurement of the full underlying vibrational fingerprint spectrum of a solid phase threat material, where individual vibrational transitions are often merged into broad absorption features by line broadening processes. We have addressed this problem using the technique of waveguide terahertz time-domain spectroscopy (THz-TDS), whereby a thin polycrystalline molecular layer is contained within a single-mode metal parallel plate waveguide, and sampled over a relatively long pathlength of several centimeters. The transverse electromagnetic mode of the parallel plate waveguide is particularly useful for spectroscopic measurements because it exhibits non-dispersive and low-loss terahertz pulse propagation. For a variety of explosives solids including trinitrotoluene (TNT) and pentaerythritol tetranitrate (PETN), and simulant materials such as the dinitrotoluenes, we demonstrate the ability of waveguide THz-TDS to resolve the previously unseen underlying terahertz vibrational fingerprint spectrum at cryogenic temperatures. The high resolution capability of waveguide THz-TDS produces vibrational line widths as narrow as 7 gigahertz. With such narrow linewidths we are able to demonstrate the measurement of line center frequencies to a precision of 1 gigahertz. For some of the threat materials as many as twenty distinguishable vibrational lines are observed in the region between 0.5 THz - 3.5 THz. Apparently, the ordered molecular layers are of sufficient crystalline quality to suppress line broadening effects that occur in standard samples such as pressed pellets. We also discuss the modeling of these highly resolved waveguide THz spectra using solid state density functional calculations.

7671-19, Session 3

Instrumentation for beam profiling in the terahertz regime

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The wealth of new science and technology opportunities found in applications of terahertz (THz) technology has fostered rapid advancement in sources, with higher power levels being demonstrated in the laboratory. These power levels are of interest to us for their potential to enhance our capabilities for non-destructive evaluation of components and imaging the interior of objects. In order to characterize the performance envelope of THz systems, we need to understand how well the THz source itself operates, characterizing important beam parameters and quantifying source performance. This test and evaluation (T&E) capability does not currently exist.

To address the current need, AEgis, AMRDEC, and UAHuntsville are developing the Terahertz Imaging Profiler Array (TIPA). The TIPA system integrates a solid-state detector technology that can be configured in an array to cover the frequency range from 0.2 to 1.2 THz. The team is developing an innovative THz instrument that provides a system capable of operating as a THz beam profiler and as a multispectral imager. The three primary components of the THz sensor array are 1) reconfigurable detector array; 2) imaging and scanning mirror modules; and 3) system control hardware and software. This talk will describe the challenges related to developing a system operating across the THz frequency regime, describe the system and system components, and show images of THz source profiles. THz images of relevant targets also will be shown and potential applications discussed.

7671-20, Session 3

Portable video rate time-domain terahertz line imager for security and aerospace nondestructive examination

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A portable video rate time-domain terahertz (TD-THz)relection line-scanner for security and aerospace destructive examination (NDE) and inspection will be described. The imager scans a line 6 inches wide and collects a TD-THz cross-sectional "B-scan" of the sub-surface structure at rates up to 30 Hz. The imager is hand-held. By rolling the scanner over surface, a radiographic 2D "C-Scan" image can be stitched together from the individual lines at a rate of 1-4 inches per second (depending on desired resolution). The case is 8.7 in. wide (12.9 in. with wheels), 12.5 in. long, and 7.9 in. high. The weight is approximately 11 lbs. The imager connects to a commercial off the shelf fiber optic coupled TD-THz control unit with a light-weight umbilical. TD-THz reflection tomography is a non-contact electromagnetic analog to ultrasound tomography (UT). TD-THz imaging is being adopted for NDE applications in aerospace and other government and industrial settings. A key capability of TD-THz imaging is that it can be used to generate 2D and 3D sub-surface images of many otherwise opaque materials. For example, NASA is currently employing TD-THz reflection NDE to examine the space shuttle external tank sprayed on foam insulation (SOFI) for voids and disbonds. Homeland security applications such as the inspection of personnel, the detection of concealed explosives, biological agents, chemical weapons, flammables, metallic and non-metallic weapons are the subject of active investigation. Experimental results of the imager applied to terrestrial radome scanning and homeland security imaging of concealed objects will be shown.

7671-21, Session 3

Development of a compact liquid cryogen-free THz heterodyne spectrometer for standoff detection of explosives

H. Richter, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Spectra of many explosive materials are dominated by a number of absorption features, which fall into the THz spectral range. These features are unique for each explosive and might therefore be used for detection and identification of explosive materials at stand-off distances up to several meters.

We will report on the development of a compact, liquid-cryogen free THz spectrometer for explosive detection and identification. The detection concept is based on THz quantum cascade lasers (QCLs) which illuminate the object under investigation at frequencies corresponding to absorption features of common explosives. The reflected and backscattered radiation is detected by a heterodyne receiver with a broadband phonon-cooled NbN hot electron bolometric mixer. In order to ensure easy and reliable operation the front-end of the receiver is integrated in a pulse tube cooler (PTC). The QCL is stabilized to an absorption line of Methanol to compensate for periodic frequency variations induced by the PTC of the heterodyne receiver in terms of sensitivity, frequency stability. The concept and the performance of the heterodyne receiver as well as first imaging and spectroscopy results at 2.5 THz will be presented. The experiments demonstrate that a solid state THz heterodyne receiver in a PTC is feasible.

7671-22, Session 3

Thermoelasticity analysis of skin tissue with the use of terahertz radiation

H. G. Suarez, Univ. EAFIT (Colombia)

When a terahertz laser generator irradiates a person, its skin gives a thermal and thermoelastic response. Solving the partial differential equations of heat conduction propagation in cylindrical coordinates and the dynamical equations of thermoelasticity with the help of special mathematical functions and laplace transformation, I obtained two different functions in dependence of one spatial coordinate and time. These two functions can be used to perform an analysis of the skin's response, and thus will help to differentiate between unhealthy skin tissue from healthy one.

7671-23, Session 3

Terahertz-optical-asymmetric-demultiplexer (TOAD)-based arithmetic units for ultra-fast optical information processing

A. K. Cherri, Kuwait Univ. (Kuwait)

To satisfy the increasingly needed operational speed in digital communication (in THz range)   and optical/optoelectronics parallel processing systems, researchers are switching from   electronics to all-optical ones.

Recently, an all-optical switch which is capable of demultiplexing Tb/s pulse trains was   reported. It consists of a nonlinear optical element asymmetrically placed within a short fiber   loop (TOAD), and operates with low-energy and it is small enough to be integrated on a chip.

In this paper, the designs of ultra-fast all-optical TOAD-based device are reported. With   the help of TOAD switches, adders and subtracters units are demonstrated. The input and the   control signals are all-optical in nature. The high speed is achieved due to the use of the   nonlinear optical materials and the nonbinary modified signed-digit (MSD) number   representation.

In contrast to the binary adder, the proposed circuits can be extended to n digit by   employing additional stages without affecting the total addition time.

The three MSD digits {-1, 0, 1} cannot be directly implemented using the two binary states of   the TOAD switches. An encoding scheme is used to transform each MSD digits into a pair of   binary bits.

Minimization technique employed to the logical equations leads to more efficient designs   and more compact optical circuit in terms of numbers of logical gates, input/outputs lines,   interconnection elements, and time delay units.

It will be reported various all-optical circuits, which are compared in terms of numbers   TOAD switches, optical amplifiers and wavelength converters. The practical implementation   of the proposed circuits is also discussed.

7671-38, Session 3

THz atmospheric transmission using a 1.35-mJ ammonia Fabry-Perot cavity terahertz pulsed laser with metallic capacitive-mesh input and output couplers

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To perform THz atmospheric transmission, it is extremely necessary to obtain firstly a high-energy pulsed THz source. In this article an efficient ammonia Fabry-Perot (F-P) cavity terahertz (THz) laser has been studied experimentally. The cavity THz laser systems consisting of a short pulse TEA CO2 laser, a pyrex waveguide tube and input and output couplers have been designed and constructed. The input and output couplers also served as sealed windows fabricated by depositing nickel capacitive metallic meshes on ZnSe and high-resistivity silicon substrates have been constructed as a F-P oscillator. Using the THz laser, the properties related to THz pulsed laser such as beam profile, delay, the minimum pump intensity, THz lasing threshold and THz atmospheric transmission have been investigated. Further, the factors such as pump intensity and gas pressure influencing the efficiency of THz laser have also been discussed. Finally, the highest output pulse energies of 1.35 mJ at 90 m operating at 1.09 kPa ammonia pressure pumped by a 402 mJ TEA CO2 laser with 9R (16) line have been generated, and photon conversion efficiencies of 6.5 percent have been achieved. Moreover, the 3.33 THz laser with 32 mm beam diameter, 1.8 mrad divergence angle and 1.08 mJ output energy has been transmitted for a maximum distance of 1.5 m in the atmosphere.

7671-40, Session 3

Ballistic electronics: breaking the barrier in terahertz speed processing

M. Margala, Univ. of Massachusetts Lowell (United States)

Novel device called the Ballistic Deflection Transistor (BDT) is presented. BDT is a unique planar device that possesses both a positive and a negative transconductance region and is capable of operating into the THz frequency regime at the room temperature. BDT is based upon an electron steering and a ballistic deflection effect. Modeling and experimental measurements have indicated that the transconductance of the device increases with applied drain-source voltage. The differential mode of operation provides two drain outputs, which depending on gate bias, are either complementary or non-complementary. This facilitates a wide variety of circuit design techniques. The extremely low gate capacitance of the planar structure predicts THz performance. We present measured results from the fabrication of a BDT NAND gate and a BDT general purpose gate, which can be configured into any two-input Boolean logic function. The measured results are further supported by an empirical model generated from a fabricated BDT output response. Future plans to facilitate large-scale integration are also discussed. Experimental dependencies of the device geometry on the performance of a novel Ballistic Deflection Transistor (BDT) in the quasi-ballistic regime are also discussed. Our Monte Carlo analysis reports on the effect of different geometry parameters on the transfer characteristic. The strength of the gate control in the InGaAs channel is analyzed. We propose different models for the surface charge density to explain the observed experimental measurements. Finally, time domain spectroscopy is used to successfully demonstrate a measurement of THz response in ballistic nanodevices at room temperature. The talk will highlight achievements accomplished during the past four years in defining new switching transistor elements, new logic structures to new sequential elements that will make this very high speed computation possible.

7671-24, Session 4

THz wave generation and imaging for industrial applications

K. Kawase, RIKEN (Japan) and Nagoya Univ. (Japan); T. Shibuya, K. Suizu, Nagoya Univ. (Japan); S. Hayashi, RIKEN (Japan)

Terahertz waves have the property of being able to pass through various objects, such as paper, vinyl, plastics, textiles, ceramics, semiconductors, lipids and powders, just like radio waves. Terahertz waves are also able to image substances, just like X-rays, although unlike Terahertz waves, they do not present risks of irradiation. The property of terahertz waves lies in moderate transmission and moderate absorption. Whereas X-rays sometimes render objects invisible because of their excessive strength of penetration, terahertz waves make things that cannot be seen with X-rays visible, because their strength of penetration is weaker. Among our research activities for THz sources, we can mention: i) Injection seeded terahertz-wave parametric generators using a microchip laser or a multi-mode laser; ii) Difference frequency generation using a DAST crystal with very high damage threshold; iii) Extremely frequency widened terahertz wave generation in Cherenkov-type radiation using a LiNbO3 slab waveguide; etc. Among our research activities for applications, we can mention: i) THz CT for the inspection of soot distribution in a ceramic filter ii) Time of flight THz reflection tomography for multi layered thin coatings; iii) THz spectroscopic imaging for the detection of illicit drugs in the envelopes; iv) Laser-THz emission microscope for semiconductor device inspection; iv) Metal mesh sensor for the measurements of molecular bindings or thin film thickness; v) Si rod waveguide sensor for the measurement of liquid; etc.

7671-25, Session 4

Grating THz laser with optical pumping

J. Khoury, B. Haji-Saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

The device physics of our THz laser design based on the Smith Purcell free electron laser with additional optical pumping is presented. In the Smith-Purcell free-electron laser, an energetic electron beam (e-beam) pumps a metallic grating to generate surface Plasmon. The interaction between the electrons in the e-beam and the electrons in the conducting grating couples the kinetic energy of the free electrons in the e-beam into an oscillation. The oscillating electrons generate an electromagnetic field, which amplifies the interaction between the electrons in the e-beam and the electrons in the conducting grating. These interactions enhance the oscillation further at the expense of the e-beam kinetic energy, which subsequently enhances the electromagnetic emission.

Our solid state optically pumped design consists of a thin layer of SiNx (or any other appropriate dielectric material) sandwiched between a corrugated structure and a thin metal (or conductor/semiconductor) layer. The lower layer is for current streaming and replacing the e-beam in the original design. The upper layer consist of two micro gratings, one for coupling the electromagnetic field in and the other for coupling out, and a nano-grating for coupling with the current in the lower layer for electromagnetic field generation. The surface Plasmon waves generated from the upper layer (by external electromagnetic field) and the lower layer (by the applied current) are coupled. Enhancement in the emission occurs when the plasmonic waves in both layers are resonantly coupled.

7671-26, Session 4

Fabrication and THz loss measurements of porous subwavelength fibers using a directional coupler method

M. A. Skorobogatiy, A. Dupuis, Ecole Polytechnique de Montréal (Canada); J. Allard, D. Morris, Univ. de Sherbrooke (Canada)

We report on design, fabrication, and characterization of the THz guiding properties of a porous subwavelength polyethylene fiber. Recently, our group has proposed an improvement over the basic subwavelength fiber design by making the fiber core porous. A porous fiber was made using a subtraction technique where part of a drawn all-solid fiber is dissolved in order to form air holes. We chose Poly(methyl methacrylate) (PMMA) as a sacrificial polymer as it can easily be dissolved in tetrahydrofuran (THF) while leaving the polyethylene (PE) intact. Furthermore, non-porous PE fibers were fabricated to serve as a benchmark for the comparison of the propagation losses. We also present a novel and non-destructive directional coupler method (DCM) to measure the fiber transmission loss. Within this method a second subwavelength fiber is used to form a directional coupler with the test fiber. This directional coupler is then translated along the length of the test fiber in order to probe its attenuation. When comparing the transmission of a 380 um diameter porous fiber and a 410 um non-porous fiber we measure, in the vicinity of 0.3THz, an attenuation coefficient of 0.01 cm-1 and 0.11 cm-1 for the porous and non-porous fibers, respectively. So the porosity of the fiber can lower the absorption loss by as much as a factor of 10. We further conducted finite element theoretical modeling of the dispersion and bending loss characteristics of porous fibers and established a broadband low-dispersion guidance regime below 0.35THz with GVD<1ps/THz cm with high tolerance to bends as small as 10cm in bending radius.

7671-27, Session 4

Transient analysis of a step-graded Gunn diode as high-power terahertz source

F. Amir, C. Mitchell, M. Missous, The Univ. of Manchester (United Kingdom)

An advanced step-graded Gunn diode physical model has been developed. The transient characteristics for a sub micron transit region device are reported. The model has been developed through joint modelling-experimental work. The > 100 GHz fundamental frequency devices have been realized to test GaAs based Gunn oscillators at sub-millimetre wave for use as a high power (multi mW) Terahertz source in conjunction with a mm-wave multiplier, with novel Schottky diodes. The epitaxial growth of both the Gunn diode and Schottky diode wafers were performed using an industrial scale Molecular Beam Epitaxy (V100+) reactor.

Physical models of the high power Gunn diode sources, presented here, are developed in SILVACO, which provides a Virtual Wafer Fabrication (VWF) simulation environment. The model was initially developed for a 77 GHz device commercially manufactured and packaged by e2v Technologies (UK) Plc, to be used in a 77GHz automotive Autonomous Cruise Control (ACC) system. Simulated IV characteristics in forward and reverse bias matched extremely well to measured data, thus validating the choice of the physical models and material parameters used. The model was then used to perform predictive modelling for the high frequency and high power devices that will be discussed in detail and presented with measured results. Finally transient characteristics would be discussed, with a focus on sub micron transit region device to establish transit region length's scaling affects.

7671-28, Session 4

Temperature dependence of nonlinear properties of semiconductors in the THz region

J. A. Tribble, Naval Air Warfare Ctr. Aircraft Div. (United States)

Nonlinear transmission properties of semiconductor materials in the infrared range is important to the continued development of these materials towards lasers and sensors for infrared countermeasures, communication and imaging. Saturation phenomena in these materials have the potential to limit laser or sensor performance and yet the

individual effects may point to new electro-optic devices. This paper will review reported ultrafast nonlinear measurements of far infrared transmission through InP, InSb and GaAs which have begun to elucidate hot carrier dynamics. Building on these reported findings, this paper will present considerations for measuring the temperature dependence of saturation effects using a THz Pump/Probe configuration.

7671-29, Session 4

High-efficiency transferred substrate GaAs varactor multipliers for the terahertz spectrum

M. Henry, B. Alderman, H. Sanghera, Science and Technology Facilities Council (United Kingdom); P. J. I. de Maagt, European Space Research and Technology Ctr. (Netherlands); D. N. Matheson, Science and Technology Facilities Council (United Kingdom)

There is a demand for millimetre wave and sub-millimetre wave power sources to be used as local oscillators in heterodyne radiometers for remote sensing, atmospheric physics and radio astronomy. An ideal source for most of these applications should exhibit high output power, efficiency, large bandwidth and high thermal stability. We report here on the design and evaluation of high efficiency frequency doublers which provide useful power at millimetre and sub-millimetre wavelengths. The active device is a single GaAs chip consisting of a linear array of 4/6 planar schottky varactors which have been subsequently transferred on to Aluminium Nitride in order to improve the power handling capability and hence the efficiency. The so-called transferred substrate multipliers improves the efficiency of the component by around 15% compared to similar designs on the original GaAs substrates. The varactor chip and quartz microstrip circuit are embedded in a split waveguide block. The transferred substrate multipliers exhibit an efficiency of around 30 % at 160 GHz for an input power of 60 mW, and a 20% efficiency at 332 GHz for an input power of 40 mW.

7671-30, Session 5

Passive millimeter-wave imaging for security and safety applications

H. Sato, Tohoku Univ. (Japan)

Imaging of concealed objects in clothes can be accomplished in a noninvasive and noncontact manner by using millimeter wave (MM-wave) passive imaging techniques. In this paper, 77 GHz millimeter wave passive imaging camera for the purpose of security is developed. In order to detect concealed objects in clothes without hindrance to flow of people at airport security checks, video rate imaging is realized using one-dimensional imaging sensor array of 25 elements and a flapping reflector. The imaging sensor is composed of antenna made of Alumina substrate, transition from slot-line to micro-strip line (balun), LNA with matching circuit, detector circuit with Schottky barrier diode (SBD) and DC circuit, and they are integrated within the width of 4 mm so as to be the size of the pixel of MM-wave image. As receiving antennas, novel antipodal Fermi antenna (APFA) having required characteristics for passive imaging such as broadband, axially symmetric directivity with desired beam width, narrow width geometry is used. In order to eliminate drift effects of imaging sensor array, novel real-time calibration method using flapping reflector is applied for MM-wave dynamic imaging. Imaging of human body with PET bottle in clothes was performed and almost clear image of body line and geometry and position of PET bottle is obtained. Imaging of human body through the fire was also performed and it is demonstrated that passive MM-wave imaging provide clear image of human body which could not be obtained by IR imaging.

7671-31, Session 5

Lab measurements to support modeling terahertz propagation in brownout conditions

S. T. Fiorino, P. M. Grice, M. J. Krizo, R. J. Bartell, S. J. Cusumano, Air Force Institute of Technology (United States)

Brownout, the loss of visibility caused by dust and debris introduced into the atmosphere by the downwash of a helicopter, currently represents a serious challenge to U.S. military operations in Iraq and Afghanistan, where it has been cited as a factor in the majority of helicopter accidents. Brownout not only reduces visibility, but can create visual illusions for the pilot and difficult conditions for crew beneath the aircraft. Terahertz imaging may provide one solution to this problem. Terahertz frequency radiation readily propagates through the dirt aerosols present in brownout, and therefore can provide an imaging capability to improve effective visibility for pilots, helping prevent the associated accidents. To properly model the success of such systems, it is necessary to determine the optical properties of such obscurants in the terahertz regime. This research attempts to empirically determine the full complex index of refraction optical properties of dirt aerosols representative of brownout conditions. These properties are incorporated into the AFIT/CDE Laser Environmental Effects Definition and Reference (LEEDR) software, allowing this program to more accurately assess the propagation of terahertz radiation under brownout conditions than was done in the past with estimated optical properties.

7671-32, Session 5

Migrating from superconducting to semiconducting YBaCuO thin film bolometers as future far-infrared imaging pixels

V. S. Jagtap, M. K. Kulsreshath, M. Longhin, Ecole Supérieure d'Electricité (France); V. Michal, STMicroelectronics (France); G. Klisnick, G. Sou, Univ. Pierre et Marie Curie (France); A. J. Kreisler, A. F. Dégardin, Ecole Supérieure d'Electricité (France)

YBa2Cu3O6+x compounds are well known to be superconducting (Super.) for x > 0.4 and semiconducting (Semi.) for lower oxygen content. In order to migrate from Super. to Semi. far-infrared bolometer technologies, we have compared the performance of 2x2 pixel arrays elaborated from both YBaCuO families. Super. YBaCuO, deposited by thermal co-evaporation at 750 °C with adequate oxygenation, was commercially provided on (001) MgO substrates. The Semi. material was deposited by sputtering close to room temperature, on both (001) MgO and SiO2/Si substrates. For the latter, thermal resistance ratio at 300 K was in the 3-5 %/K range. The bolometric pixels were in the shape of meanders, each covering an effective area of 1 square mm. Pixel responsivity (amplitude and phase) and noise level were studied in the 1 Hz to 3 MHz modulation frequency range by using a 850 nm VCSEL solid state laser as first validation step. Thermal crosstalk was studied and discussed as a function of the modulation frequency, so to evaluate the adequate frame rate. The readout circuitry was designed by aiming at low level and large bandwidth amplifiers to allow multiplexing of pixel signals. CMOS ASIC circuitry was designed to cover the 70-300 K temperature range. Preliminary tests exhibited 40 dB gain, 17 MHz bandwidth and 2 nV/root-Hz at 77 K (4 nV/root-Hz at 290 K). The technological and design issues to switch from a cooled to an optimized uncooled YBaCuO device concept will be discussed.

7671-33, Session 5

Terahertz imaging radar at long standoff ranges

K. B. Cooper, N. Llombart, R. J. Dengler, G. Chattopadhyay, I.

Mehdi, Jet Propulsion Lab. (United States) and California Institute of Technology (United States); P. H. Siegel, Jet Propulsion Lab. (United States)

The NASA Jet Propulsion Laboratory (JPL) , California Institute of Technology, has developed an ultra-wide bandwidth radar operating at 660-690 GHz that can penetrate clothing and detect multiple targets with sub-cm range resolution. With an aperture of 1 m in diameter, cm-scale cross-range resolution is also possible at a standoff range of 25 m. Fast beam scanning is achieved by the rapid deflection of a subreflector in a confocal Gregorian optical geometry, and fast signal processing has been implemented in both a CPU and an FPGA. These features permit person-borne concealed weapons to be detected rapidly and with high fidelity. In this talk, JPL's THz imaging radar will be described, and through-clothes imagery at standoff ranges up to 25 m will be presented.

7671-34, Session 5

A microbolometer-based THz imager

L. Marchese, L. Le Noc, B. Tremblay, F. Dupont, F. J. Williamson, Y. Desroches, L. Mercier, C. Alain, H. Jeronimek, A. Bergeron, INO (Canada)

THz imaging is a very promising field rapidly growing in importance. This expanding field is at its early stage of development but already a large number of applications are foreseen. THz imaging promises to be a key technology in various fields, such as defense & security where it can be used to defeat camouflage. Based on its many years of experience in uncooled bolometers technology, INO has developed, assembled and characterized a prototype THz imager. The camera's 160 x 120 pixel array consists of pixels with a 52 µm pitch that have been optimized for the THz region. INO's IRXCam camera electronics is used to address every other detector resulting in an effective pixel pitch of 104 µm and effective array size of 80 x 60 pixels. A custom f/1 THz lens barrel completes the design. Characterization of the imager is performed with a calibrated 3 THz quantum cascade laser set-up.

This paper reviews the design and performance evaluation of the microbolometer detectors and provides a description of the imager design and its calibrated characterization set-up. The performance characteristics of the THz imager are then discussed. Preliminary images produced with the camera are further presented.

7671-35, Session 5

Progress toward handheld terahertz spectrometry

B. J. Schulkin, T. D. Tongue, Zomega Terahertz Corp. (United States); D. Brigada, Rensselaer Polytechnic Institute (United States); X. Zhang, Rensselaer Polytechnic Institute (United States) and Zomega Terahertz Corp. (United States)

The application of THz sensing and imaging to standoff detection and identification is one of the most challenging and desired research topics. Many energetic, organic and pharmaceutical compounds have their molecular fingerprints and phonon signatures in the terahertz frequency range. However, real-time identification presents several technical challenges before in-the-field applications in security, pharmaceutical and NDE areas can be realized. In this paper, we present results using the mini-Z, a compact commercial THz TDS platform, to perform stand-off real-time detection and identification of 8 selected samples in pressed-pellet, powder, and under cloth cover.

In the experiment, the mini-Z was configured for normal-incidence reflection geometry, using a 50-µm LT-GaAs photoconductive antenna with a 100 kHz, 120V AC bias and 1mm thick ZnTe crystal for balanced detection. Samples were placed on a metal mirror for bulk-reflection measurement. Samples were composed of HDPE powder mixed with up to 5% concentration (by weight) of the target compound, and pellets

were formed using a 5-ton press, while powders were placed directly on the mirror for measurement. Based on the instrument dynamic range and the strength of the absorption feature for a target compound, we are able to determine the minimum concentration required for detection.

For real-time (5Hz) measurement using the mini-Z, concentrations as low as 25μg/cm2 of RDX, 2HBP and 2,4 DNT can be detected.

This work also allows us to determine the Relative Operating Characteristic (ROC) curve, which shows the trade-off between false-positive and false negative rates for different acquisition times and sample preparation. Based on measurements acquired at 5Hz and 1Hz, the possibility of stand-off explosive (RDX, PETN, etc.) detection with better than 0.1% false positive rate is discussed.

7671-36, Session 5

THz all-electronic 3D imaging for safety and security applications

B. M. Fischer, Y. Demarty, M. Schneider, Institut Franco-Allemand de Recherches de Saint-Louis (France); T. Löffler, A. Keil, H. Quast, SynView GmbH (Germany)

The ability of terahertz and millimeter-wave imaging to detect suspicious hidden objects underneath clothing or in luggage has led to increased interest in these techniques. Several approaches have been demonstrated in the past few years, amongst which active, all-electronic terahertz imaging has proven to be particularly adapted for safety and security applications. It combines a large dynamic range and the ability to perform range measurements with increased spatial resolution. At the French-German Research Institute of Saint Louis (ISL), we used an all-electronic 3D imaging system in the range from 230 GHz to 320 GHz (SynView Scan 300) for a comprehensive study on various suspicious objects and cloth types. We demonstrate an enhanced detection capability for hidden suspicious objects if the range information is extracted and visualized in appropriated ways.

Although all-electronic imaging is significantly faster than many passive imaging techniques, the actual scanning duration of currently approximately 15 minutes for a scan range of 600 by 700 mm2 is still too slow for many safety applications.

In the outlook of our presentation we will therefore introduce novel concepts aiming at active range imaging with video-frame-rates.

7671-37, Poster Session

Terahertz wave opto-mechanical scanner for security application

C. Zhang, Capital Normal Univ. (China); C. Deng, Beijing Institute of Technology (China)

This paper describes a new opto-mechanical scanner that is hopeful about future apply for terahertz(THz) imaging in security applications. The target of using this scanner is portal screening of personnel for high-resolution imaging of concealed threat objects. It is not only applied to active THz imaging but also applied to passive THz imaging. THz radiation can penetrate many materials that are opaque to visible and infrared light, such as plastics, cardboard, textiles and so on. Compare to microwave radiation, THz radiation have a shorter wavelength. it has a higher spatial resolution.Compared to X-ray, THz photon energy is only 4.1 milli-electron volt.it is harmless to living organisms.Compared to infrared,THz radiation is less sensitive to thermal background noise.So the Thz imaging technology has a potential to be applicable in security inspection at airports, stations and other public place. Now, the most THz imaging system work at point to point mechanical scan pattern. The speed of this reater scan is too slow to apply to practical field. Two dimension THz array detector can be applied to real time imaging. But at present their cost is prohibitively high. Fortunately low cost, high performance, opto-mechanically scanner are able to meet the current requirements. An opto-mechanical scanner should be able to rapidly

scan a 2-D image of the scene. It also should have high optical efficiency so that an image system can achieve the required thermal sensitivity with the minimum number of receivers. These ensures that it can easily operate at active or passive. The opto-mechanically scanning can meets these requirements and is being developed into a high performance, low-cost prototype system that hopefully will meet the present and future needs for THz imaging.

7671-39, Poster Session

A complex structure GaAs waveguide emitter with a periodic variation along the propagation direction for generation of terahertz radiation

T. Yang, R. Li, J. Wang, D. Yang, M. Sang, Tianjin Univ. (China)

A hybrid corrugated asymmetric dielectric planar waveguide made up of nongrating sections and grating sections is proposed and designed as a new potential terahertz radiation emitter. In each nongrating section, a core layer of GaAs is sandwiched between air and the substrate of AlxGa1-xAs, and in each grating section a second-order rectangular grating is etched on the interface of GaAs. Electromagnetic waves in terahertz band could be generated in the nongrating sections pumped longitudinally by a pulsed fiber laser at the center wavelength of 1550nm based on optical rectification process. The calculation shows that coherent length of this nonlinear optical process can be more than 950 mm for the component of 2THz when the thickness of core layer of GaAs is about 145μm and the value of x in substrate of AlxGa1-xAs is set to be 0.1. The conclusion is inferred that the phase matching can be reached by exploring the waveguide mode dispersion because the coherent length is only 0.78mm at 2THz in bulk of GaAs for the same nonlinear process. In following grating section, a rectangular second-order grating structure is introduced to diffract transversely THz electromagnetic waves propagating longitudinally into free space of air in order to reduce the dielectric absorption and to form THz radiation. Calculations show that the coupling efficiency could be more than 60% when the length of grating section is about 1 mm covered with 25 grating pitches and the depth of the 50% duty factor rectangular grating is 36μm. Finally, the power of terahertz radiation is expected to scale up by adding more units of alternating nongrating section and grating section along with the longitudinal direction of this waveguide device.

Conference 7672: Polarization: Measurement, Analysis, and Remote Sensing IX

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Polarization: Measurement, Analysis, and Remote Sensing IX

7672-01, Session 1

Linear fusion of passive polarization-based imagery for effective discrimination and recognition of real targets in the presence of multiple identical decoys

A. M. El-Saba, Univ. of South Alabama (United States)

There are numerous advantages of using polarization-based imagery in target recognition applications. A polarization-based imagery is generally more sensitive to the nature of the scattering surface of targets than pure intensity imagery. This unique behavior is very useful in highlighting certain target attributes of interest. This paper presents a simple approach for linear fusion between passive polarization-based imagery for effective discrimination and recognition of real targets in the presence of multiple identical decoys.

7672-02, Session 1

3D shape reconstruction of optical element using polarization

M. Vedel, N. Lechocinski, S. Breugnot, Bossa Nova Technologies (United States)

We present a novel polarization based metrological method of 3D shape measurement for in-line control of optical surfaces and control of highly aspherical optical surfaces. This technique is fast, non contact, high resolution, alignment free and with unprecedented dynamic. It has the potential to reach tens of nanometers accuracy. In this paper we show that a polarization imaging camera combined with an un-polarized illumination and 3D reconstruction algorithm lead to the 3D reconstruction of optical element (regular lens and aspheric lens) and the measurement of their parameters. The optical element to be measured is placed in a diffusive integrating sphere and illuminated by un-polarized light. The reflection of the un-polarized light by the optical element gets partially polarized. A polarization camera captures the image of the optical element and measures the polarization state of each pixel in real time. The Degree Of Light Polarized and the Angle Of Polarization parameters are related to the geometry of the optical element. The 3D shape of the optical element is reconstructed using dedicated software. This technique is totally adapted to in-line control thanks to its speed and insensitivity to alignment. The architecture of the hardware, calibration results and sensitivity measurements is presented. A new algorithm based on polarization imaging leading to the construction of the gradient field is described. Finally, experimental results and observations as well as possible further steps and new applications are discussed.

7672-03, Session 1

Pose estimation of unresolved targets using polarimetric imaging

M. G. Gartley, Rochester Institute of Technology (United States); P. S. Erbach, L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States)

Polarimetric remote sensing has demonstrated utility for improving contrast between man-made targets and complex backgrounds. More specifically, polarimetric signatures of man-made targets can be useful for cueing analysts in wide-area search applications. However, taking the target cueing to the next level of identification and tracking may require tasking of other sensing modalities. We present research that

aims to understand what pose information might be extracted from the polarimetric signatures of under-resolved targets. Through experimentally collected and simulated imagery, we examine the variation in target signatures with respect pose and collection geometry aiming to extend the intelligence value of polarimetric imagery.

7672-04, Session 1

MidIR and LWIR polarimetric sensor comparison study

K. P. Gurton, M. A. Felton, Jr., U.S. Army Research Lab. (United States); R. Mack, Air Force Research Lab. (United States); C. Farlow, Digital Fusion Inc. (United States); L. Pezzaniti, Polaris Sensor Technologies, Inc. (United States); M. W. Kudenov, College of Optical Sciences, The Univ. of Arizona (United States); D. LeMaster, Air Force Research Lab. (United States)

We present a comparative study involving 5 distinctly different polarimetric imaging platforms that are designed to record calibrated Stokes images (and associated polarimetric products) in either the MidIR or LWIR regions. The data set used in this study was recorded during April 14-18, 2008 at the Russell Tower Measurement Facility, Redstone Arsenal, Huntsville, Al. Four of the five camera systems considered were designed to operate in the LWIR (approx. 8-12µm) and used either cooled Mercury Cadmium Telluride (MCT) focal-plane-arrays (FPA), or a near room temperature microbolometer. The lone MidIR polarimetric sensor was based on a liquid nitrogen (LN2) cooled Indium Antimonide (InSb) FPA resulting in an approximate wavelength response of 3-5µm. The comparison suite of cameras were comprised of the following optical design(s); a LWIR "super-pixel" or division-of-focal plane (DoF) sensor, two LWIR spinning-achromatic-retarder based sensors, one LWIR division-of-amplitude (DoAM) sensor, and one MidIR division-of-aperture (DoA) sensor. Cross sensor comparisons were conducted by examining calibrated Stokes images (i.e., S0, S1, S2 and degree-of-linear polarization (DOLP)) recorded by each sensor, for a given target, at approximately the same test periods to ensure uniformity across platforms for environmental changes in the optical background, i.e., ambient radiance. Where applicable, additional target detection algorithms will be applied to the image set for each polarimetric sensor for further comparison, e.g., conventional receiver operating characteristic (ROC) curve analysis and an effective contrast ratio between the target and background.

7672-05, Session 2

A review and comparison of two bolt-on polarimeter optics kits for COTS MWIR cameras

P. S. Erbach, L. Pezzaniti, A. Lompado, J. Vaden, J. Reinhardt, M. Roche, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); H. S. Lowry, Aerospace Testing Alliance (United States)

A majority of the infrared (IR) imaging polarimeters have, in the past, been designed with optics and fixtures that attach directly to the cold clamp or cold finger of research-grade IR cameras with pour fill LN2 dewars. However, the commercial market for chilled IR cameras is dominated by IR camera systems with Integrated Dewar Cooler Assemblies (IDCA) or Detector Dewar Cooler Assemblies (DDCA). Therefore, Polaris Sensor Technologies, Inc. has developed two imaging polarimeter optics kits that "bolt-on" to a COTS camera housing. The two cameras perform polarimetric imaging under slightly different operating modalities. One polarimeter employs a warm rotating polarizer in front of the cold stop

and the other polarimeter employs chilled fixed polarizers and a warm rotating retarder in front of the cold stop. This paper presents a review and comparison of performance these two polarimeter optics kits.

7672-06, Session 2

SPITFIRE multiband short-wave and mid-wave polarimetric camera

H. J. Patel, R. Mack, D. LeMaster, J. Harris, Air Force Research Lab. (United States); D. P. Forrai, L-3 Communications Cincinnati Electronics (United States)

Polarimetric sensors are valued for their capability to distinguish man-made objects from surrounding clutter. The SPITFIRE (Spectral Polarimetric Imaging Test Field InstRumEnt) polarimetric camera is designed to function in multiple bands in the Short Wave Infrared (SWIR) and Mid-Wave Infrared (MWIR) regions. SPITFIRE is a Stokes micro-grid polarimetric system with a 4 band spectral filter wheel. The focal plane array (FPA) as well as the filter wheel are located in a dewar which is cooled via liquid nitrogen. By cooling the band-pass filter to the same temperature as the FPA, self-emission noise is decreased.

7672-07, Session 2

Demonstration of a snapshot imaging spectropolarimeter based on polarization gratings

J. Kim, M. J. Escuti, North Carolina State Univ. (United States)

We have introduced the concept of a snapshot imaging spectropolarimeter based on anisotropic diffraction gratings known as polarization gratings (PGs). By numerical modeling, we showed instrument can acquire dispersed and highly polarized diffractions of a scene on a single focal plane array since PGs efficiently and uniquely transmit only three diffraction orders that are linearly proportional to incident light's Stokes vector. In this paper, extendable system matrix is developed which can be used for different dispersion patterns with various configuration of multiple PGs. Moreover, our first type of imaging spectropolarimeter is calibrated and experimentally demonstrated with screen generated scene having spectral and polarization variation. We also explore different dispersion patterns as changing a configuration of multiple PGs. We explore and evaluate different dispersion patterns as changing a configuration of multiple PGs with a view toward an optimal practical system, and derive critical design limitations.

7672-08, Session 2

White-light Sagnac interferometer for snapshot polarimetric and multispectral imaging

M. W. Kudenov, M. E. L. Jungwirth, E. L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States); G. R. Gerhart, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States)

The theoretical and experimental demonstration of a dispersion-compensated polarization Sagnac interferometer (DCPSI) is presented. An application of the system is demonstrated by substituting the uniaxial crystal-based Savart plate (SP) in K. Oka's original snapshot polarimeter implementation with a DCPSI. The DCPSI enables the generation of an achromatic fringe field in white-light, yielding significantly more radiative throughput than the original quasi-monochromatic SP polarimeter. Additionally, this interferometric approach offers an alternative to the crystal SP, enabling the use of standard reflective or transmissive materials. Advantages are anticipated to be greatest in the thermal infrared, where uniaxial crystals are rare and the at-sensor radiance is often low when compared to the visible spectrum. The theoretical and experimental development of the DCPSI, created through the use of two blazed diffraction gratings, is provided. This includes reconstruction techniques, in addition to the application of the system as a polarimetric imager. Lastly, field test data from the sensor are also provided, and applicability of the interferometer to snapshot multispectral imaging is highlighted.

7672-09, Session 2

Continuous outdoor operation of an all-sky polarization imager

N. Pust, B. Staal, J. Johnson, A. Dahlberg, J. A. Shaw, Montana State Univ. (United States)

An all-sky imager has previously been reported that was designed and built at Montana State University to study the variability of polarization with atmospheric conditions. This imager records all-sky images and generates Stokes vectors at each of 1 MPixels across the full sky dome at five wavelengths from 450 to 700 nm. The imager has been modified to operate with a custom-designed sun occulter in an enclosure that is environmentally controlled with thermoelectric heater/cooler elements. It has operated continuously during daylight hours since June 2009, obtaining data in a wide range of conditions that were previously difficult to obtain with episodic outdoor deployments. This paper describes the design of the instrument and environmental housing, and shows examples of the data being obtained.

7672-10, Session 2

Stokes imaging polarimetry using a single ferroelectric liquid crystal modulator

L. Gendre, A. Foulonneau, L. Bigue, Univ. de Haute Alsace (France)

We already implemented an imaging polarimeter able to capture at high-speed the full information about linear polarization of a monochromatic light beam (namely its first three Stokes parameters). The polarizing element was a single ferroelectric liquid crystal cell, acting as a half-wave plate (therefore as a polarization rotator) at its design wavelength. In this paper, we report the improvement of our system in order to grab the full Stokes information, including the fourth Stokes parameter. The procedure consists in two operations. First, optimally controlling our polarization component with an additional fourth voltage level. Second, shifting the wavelength operation in order to get benefit of the device chromatic behavior: away from its design wavelength, the device does not behave as a half-wave plate any longer, and with proper level control, the analysis matrix of our polarization state analyzer (consisting of the liquid crystal cell and of a fixed linear polarizer) can reach rank 4. Therefore, elliptical polarization can be fully analyzed, as it could be with a nematic liquid crystal device, but at a much higher frame rate.

Results of operation above 200 Hz are provided.

7672-11, Session 3

Novel thin film-based polarization components

L. Wang, R. J. Beeson, T. Erdogan, Semrock Inc. (United States)

Described are a series of novel thin-film based polarization components with unique capabilities. These components, either independently or in combination with variation of the angle of incidence, provide capabilities such as extremely high contrast ratio within a bandpass filter, multi-wavelength polarization splitting, variable effective birefringence, and polarization switching. A laser-grade polarizing bandpass filter combines

a polarization contrast ratio greater than 1,000,000:1 (extinction ratio < 10-6) with a bandpass filter having overall transmission > 93%, very steep edges, and high out-of-band blocking and high laser damage threshold (> 1 J/cm2). A multi-wavelength polarizer provides the same contrast ratio simultaneously at multiple laser wavelengths. A tunable waveplate provides full relative retardance (0 to 180 degree) with angle tuning over a 10 degree range. Finally, a polarization switching filter alternates between 4 states with mechanical rotation: high s- and p-polarization blocking, high s- and p-polarization transmission, and simultaneous transmission and blocking of different polarizations with > 1,000,000:1 contrast ratio.

These new polarization filters are useful for a wide variety of applications where precise polarization control, discrimination, and detection are critical. These include laboratory laser systems, laser material processing, polarization diversity detection in communications and rangefinding, and fluorescence polarization and second-harmonic-generation imaging.

7672-12, Session 3

Evaluation of infrared (3-12μm) wire grid polarizers

D. H. Goldstein, P. S. Erbach, Polaris Sensor Technologies, Inc. (United States)

We have evaluated wire grid polarizers for the thermal infrared in the 3 to 12μm wavelength range. Wire grid structures are an effective means of producing infrared polarizers with short optical path and having large acceptance angles. Performance of two sets of polarizers manufactured by Moxtek, for the 3-5μm and 8-12μm wavelength ranges, were tested in a Mueller matrix spectropolarimeter and found to have transmission ratios on the order of 103.

7672-13, Session 3

Tunable liquid crystal filters including variable FWHM control

P. A. Searcy, P. Wagner, R. A. Ramsey, J. Powell, T. G. Baur, Meadowlark Optics, Inc. (United States)

Meadowlark Optics has successfully built and demonstrated a liquid-crystal based tunable filter with novel FWHM tunability. This allows separate control over both the location of a narrow spectral bandpass and the width of the bandpass function. This non-mechanical, imaging filter thus enables random access of the visible to near IR spectrum and also controlling the specificity of the light. We will discuss both the relative trade-offs in this filter design space and present data from functional units.

In detail, we use combinations of well-known Solc, Lyot and similar filter stages separated by linear polarizers to allow much larger free spectral ranges (finesses) to be achieved. Furthermore, by having additional elements (which will be covered in the talk), we are able to change the FWHM into different widths allowing the user two degrees of freedom.

7672-14, Session 3

Integrated high-resolution division of focal plane image sensor with aluminum nanowire polarization filters

V. Gruev, R. Perkins, Washington Univ. in St. Louis (United States)

We present our latest research efforts in division of focal plane polarization image sensors. Our novel polarization image sensor integrates CCD imaging elements with aluminum nanowire polarization filters at the focal plane. The aluminum nanowires are fabricated using interference lithography in order to create 70nm wide nanowires with

130nm pitch. The aluminum nanowires are organized in four distinct pixel orientations; hence composing a microgrid polarization array with pixel oriented at 0o, 45o, 90o and 135o. The pitch of each microgrid pixel is 7.4 m and it is matched to the pitch of the CCD image sensor. The monolithic integration of the microgrid polarization array with one mega pixel CCD image sensor allows for imaging of polarization properties of partially polarized light at 60 frames per second. The raw image data from the image sensor is streamed to an FPGA processor, where an optimized pipelined digital signal processing is performed. Some of the processing on the FPGA include interpolation, per pixel gain and offset correction, computation of the first three Stokes parameters and computation of the degree and angle of polarization. The intensity, degree and angle of polarization are provided in false color representation to the end user. The power consumption of the image sensor is 280mW with extinction ratios of ~30. The imaged sensor is used for various applications, including imaging in shadow, hazy and foggy conditions and data from these experiments will be presented.

7672-15, Session 4

Performance assessment of optical registration technique for imaging polarimeters

G. A. Finney, M. W. Jones, Kratos Defense & Security Solutions, Inc. (United States)

Deployable polarimetric imaging systems often use 2x2 arrays of linear polarizers at the pixel level to measure the polarimetric signature. This architecture referred to as micro-grid polarizer array (MPA). MPAs are either bonded to or fabricated directly upon focal plane arrays. A key challenge to obtaining polarimetric measurements of sub-pixel targets using MPAs is registering the signals from each of the independent channels. Digital Fusion Solutions, Inc has developed a micro-optic approach to register the fields of view of 2x2 subarrays of pixels and incorporated the device into the design of a polarimetric imager. The results of the first fabrication run will be presented.

7672-16, Session 4

Realization of polarization-based optical code division multiple access system using code-hopping technique

A. Saha, S. Mandal, S. Ghosh, B.P. Poddar Institute of Management & Technology (India)

This report forms a part of systematic investigation on the Optical Code Division Multiple Access (OCDMA) system using polarization optics. To date, most of the OCDMA systems utilize unipolar Walsh or Gold-Kassami code. This proves to be a disadvantage from the standpoint of bandwidth as bipolar data has to be encoded in its equivalent unipolar form resulting in increase of total number of bits. In this communication a novel technique is proposed that directly uses bipolar Walsh coding. We represent 1 and -1 in Walsh code by two orthogonal states of polarization. The electro-optic effect on the polarizing device changes the states of polarization which facilitates dynamic masking by code-hopping, a technique to maintain high degree of data security. A theoretical analysis in terms of capacity of the system is computed. Here, different stations are assigned different wavelengths.

7672-17, Session 4

Calibration of a visible polarimeter

M. C. Gibney, ITT Corp. (United States)

The calibration of a visible polarimeter is discussed. Calibration coefficients that provide a complete linear characterization of a

polarimeter are represented in this paper by the analyzer vector, where sensor response in counts is given by the dot product of the analyzer vector and the incoming Stokes vector. Using the analyzer vector to represent the effect of the sensor on the incoming Stokes vector, we can include elements of the generated Stokes vector in the fit used to estimate the analyzer vectors/calibration coefficients. This technique allows us to alleviate some of the strict requirements usually levied on the source used to generate the calibration Stokes vectors, such as source temporal stability. A discussion of how these techniques are applied to IR polarimetric sensors will also be touched on.

7672-18, Session 4

Parallelization of polarization state generation and detection for fast Mueller matrix polarimetry

S. Tripathi, K. C. Toussaint, Jr., Univ. of Illinois at Urbana-Champaign (United States)

Muller matrix polarimetry (MMP) has been used to characterize a variety of materials such as semiconductors, nanostructured materials, and biological tissues. However, existing MMP require the measurement of time series data because the respective processes of polarization state generation and detection are implemented sequentially. This limits the speed with which samples can be characterized, thereby limiting use in the study of dynamic processes such as thin film growth. Here we discuss some ways to parallelize the polarization state generation and detection processes so that the data collected at a single instant of time is sufficient to extract the Mueller matrix elements. Consequently, we present rapid Mueller matrix polarimetry (RAMMP), which can extract twelve Muller matrix elements from a single intensity image in real time and with high spatial resolution. With RAMMP polarization state generation has been achieved by using vector beams, which exhibit spatially inhomogeneous polarization. This is the first report on the use of vector beams in polarimetry to enhance the polarization diversity. To parallelize polarization state detection a microscope/array detector setup has been combined with a specialized algorithm that simultaneously utilizes information from multiple spatial regions of the array detector. Several different samples including magnetically active metamaterials have been numerically studied with this approach showing its versatility.

7672-19, Session 4

Complete polarization state generator with one variable retarder and its application for fast measuring two-dimensional birefringence distribution

M. I. Shribak, Marine Biological Lab. (United States)

We developed the complete polarization state generator, which principal configuration includes one rotatable polarizer and one variable retarder. The orientation angle of polarization ellipse equals to half retardance of the variable retarder, and its ellipticity angle corresponds to the polarizer azimuth. The proposed generator can be used for quantitative orientation-independent differential polarization microscopy employing polarized light with the same ellipticity and different orientation angles. For example, LC-polscope birefringence imaging system, which is currently on the market, operates with two variable retarders. The proposed microscope can work with 4-frame algorithm used by the LC-polscope. Also we describe new 3-frame symmetrical algorithm.

7672-20, Session 5

Methods in arthropod retinography for evaluation of spectral polarization sensitivity

M. F. Wehling, Air Force Research Lab. (United States); D. H. Goldstein, Polaris Sensor Technologies, Inc. (United States)

We describe apparatus and methods to measure the sensitivity of arthropod eyes to wavelength and polarization. While these general methods are well-known in the retinography community, they are less familiar to the general optics community. Measurement of polarization sensitivity is particularly uncommon even among retinographers, and our research plan and results are detailed.

7672-21, Session 6

Comparison of linear polarization between man-made objects and natural clutter background for polarimetric LWIR imagery

L. E. Roth, M. Woolley, J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

In recent years there has been increased interest in polarimetric applied to terrestrial remote sensing problems because of its ability to detect man-made objects in a natural cluttered background. However, adverse weather limits the ability to detect such man-made objects in a natural cluttered background.

This paper will discuss results of a multi-day adverse weather study in which radiometrically calibrated polarimetric and conventional thermal imagery is recorded in the LWIR to identify/compare the behavior of the linear polarization of man-made objects to that of the background throughout the day and for various weather conditions. Imagery is recorded with an uncooled achromatic retarder LWIR polarimetric sensor to perform the polarimetric filtering. The images used in this study include the S0, normalized S1, and normalized S2 Stokes images of a scene containing man-made objects and the natural background. In addition, relevant meteorological parameters measured during the test period include: air temperature, ambient loading in the LWIR, relative humidity, and cloud cover, height, and density.

It is our objective to show how the S1 and S2 data varies due to the meteorological data that was encountered during the data collection. Analysis of the S1 and S2 output surfaces and conclusions will be demonstrated on the proposed paper.

7672-22, Session 6

Importance of polarimetric radiative transfer modeling for non-polarimetric imaging applications

R. P. Kauffman, Lockheed Martin Management & Data Systems (United States); M. G. Gartley, Rochester Institute of Technology (United States)

Radiative transfer is commonly treated as a propagation of unpolarized, scalar radiometric quantities. A more thorough radiative transfer approach utilizes polarimetric quantities, such as Stokes vectors and Mueller matricies, but is usually only applied in situations where the imaging sensor is purposely discriminating polarimetric information. We examine the importance of utilizing polarimetric radiative transfer in situations where the sensor is not intentionally discriminating polarimetrically. When the primary irradiance load on a scene target is unpolarized (such as the solar irradiance), a full polarimetric treatment of the radiative transfer process is not warranted. However, in situations where the primary irradiance load has an appreciable level of polarization (such as sky irradiance), utilization of a polarimetric radiative transfer

model is warranted and provides a more accurate treatment of the first principles nature of how light propagates. We investigate this effect by performing target detection of shadowed man-made objects in both simulated and real imagery. A comparison of the resulting ROC curves is presented for both polarized and un-polarized radiative transfer methods.

7672-23, Session 6

Polarized light in a coupled atmosphere-ocean system

D. J. Gray, U.S. Naval Research Lab. (United States); J. T. Adams, ISPA Technology (United States)

Polarimetry has the potential to greatly enhance the capabilities of visible and near-IR remote sensing systems. But one of the largest hindrances of operating in this spectral region is the confounding effects of the atmosphere. The situation becomes more complitcated when operating in a marine environment, where surface reflections and subsurface scattering futher complicates the polarimetric signal. The purpose of this study is to examine the effects of the atmosphere and ocean on the polarimetric light field in a coupled atmosphere-ocean. We developed a set of polarimetric radiative transfer codes to model the polarization effects of the light field in a coupled atmosphere-ocean system. Our focus is specifically on remote sensing of the oceans. The combined effects of solar angle, viewing geometry, and sensor altitude are investigated to find optimal viewing conditions for polarimetric remote sensing. We look explicitly at the effects of different aerosol and hydrosol types and concentrations. The effects of wind-blown capiliary waves on the surface are also investigated. Results are presented for both in-water and above water sensors.

7672-24, Session 6

Lidar polarization discrimination of bio-aerosols

X. Cao, Royal Military College of Canada (Canada); G. A. Roy, Defence Research and Development Canada (Canada); R. Bernier, Les Instruments Optiques du St-Laurent Inc. (Canada)

Lidar polarization discrimination is usually based on the fact that the backscattering from spherical particles does not depolarize the light while non spherical particles do depolarize the light. The discrimination of non spherical particles based on their depolarization signature is a difficult task because the depolarization signatures are quite alike. However, multiple wavelengths depolarization measurements could in principle allow discrimination because of the different penetration depth into the biological material.

Lidar bio-aerosols discrimination based on depolarization signature is presented herein. The measurements were performed over a large variety of pollens at 355nm, 532 nm, 1064 nm and 1570 nm. Linear and circular polarizations were performed.

In a previous work, we have shown that, under multiple scattering conditions, the backscattered light of water droplet clouds (when illuminated with linearly and circularly polarized light) shows a simple mathematical relationship between the linear and circular depolarization ratio [1]. Because, to some extent, the depolarization of light by matter can be seen as a multiple scattering process we present an analysis based on departure from the relationship established for water droplet under multiple scattering.

[1] G. Roy and N. Roy, "Relation between circular and linear depolarization ratios under multiple scattering conditions", Appl. Opt. 47, 6563-6579 (2008).

7672-25, Session 6

Contrast evaluation of the polarimetric images of different targets in turbid medium: possible sources of systematic errors

T. Novikova, Ecole Polytechnique (France); A. Bénière, F. Goudail, Institut d'Optique Graduate School (France); A. De Martino, Ecole Polytechnique (France)

Subsurface polarimetric (differential polarization, degree of polarization or Mueller matrix) imaging of various targets in turbid media show image contrast enhancement compared with the total intensity measurements. The image contrast depends on the target immersion depth and on both target and background medium optical properties, such as scattering coefficient, absorption coefficient and anisotropy. The differential polarization image contrast is usually not the same for circularly and linearly polarized light.

We performed the numerical Monte Carlo modelling of backscattering Mueller matrix images of reflecting, scattering and absorbing targets positioned at different depths within the container filled with the polystyrene particle suspension in water. In both laboratory experiments and numerical simulations the shape, the dimensions of the container and the material of container walls are not always reported. We found, however, that depending on the photon transport mean free path in the scattering medium, those parameters, as well as the fact of combining targets within one recipient could all be the sources of significant systematic errors in the polarimetric image contrast evaluation. Thus, the proper design of experiment geometry is of prime importance in order to remove the sources of possible artefacts in the image contrast evaluation and to make a correct choice between linear and circular polarization of the light for better target detection.

7672-26, Session 7

Dynamic scene generation, multimodal sensor design, and target tracking demonstration for hyperspectral/polarimetric performance driven sensing

M. D. Presnar, A. D. Raisanen, D. R. Pogorzala, J. P. Kerekes, Rochester Institute of Technology (United States); A. C. Rice, Numerica Corp. (United States)

Simulation of moving vehicle tracking has been demonstrated using hyperspectral and polarimetric imagery (HSI/PI).

First, a MODTRAN4-P polarized atmosphere, polarized-BRDFs of object materials, and moving vehicle content were utilized along with RIT's Digital Imaging and Remote Sensing Image Generation (DIRSIG) Megascene-1 model to generate hyperspectral Stokes-vector video frames of a synthetic urban scene collected by an orbiting aerial platform's imaging sensor.

Second, a micromirror-based multi-object spectrometer (MOS) model was converted into a hybrid division-of-focal-plane imaging sensor designed for coregistered HSI/PI aerial remote sensing. A pixel-sized aluminum wire-grid linear polarizer atop a silicon detector was designed and simulated using COMSOL to measure its transmittance, extinction ratio, and diattenuation responses in the presence of an electric field. Wire diameters and wire-grid spacings designed for SWIR wavelengths are fabricatable using common deposition and etching processes, while smaller wire diameters and spacings appropriate for VNIR wavelengths are within reach using state-of-the-art lithography tools. Oblique DIRSIG video frames were propagated through a sensor model boasting an array of 2x2 superpixels containing both micropolarizers atop detector pixels and micromirrors. Both micromirror-relayed panchromatic imagery and micropolarizer-collected polarimetric imagery processed using Fesenkov's method were orthorectified onto Megascene's base map via the photogrammetric collinearity equation.

Third, panchromatic and degree-of-polarization (DoP) orthorectified sensor output imagery were fed to a feature-aided target tracker to perform multimodal adaptive performance-driven sensing of moving vehicle targets. Hyperspectral responses of target pixels were measured via the sensor's micromirror-based MOS functionality to aid tracking. Track performance case studies were performed using panchromatic and DoP sensor imagery.

Past SPIE papers: 73340J & 73340M.

7672-27, Session 7

Comparison of the inversion periods for MidIR and LWIR polarimetric and conventional thermal imagery

M. Felton, Jr., K. P. Gurton, U.S. Army Research Lab. (United States); J. L. Pezzaniti, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); L. E. Roth, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

We report the results of a multi-day diurnal study in which radiometrically calibrated polarimetric and conventional thermal imagery is recorded in the MidIR and LWIR to identify and compare the respective time periods in which minimum target contrast is achieved. The MidIR polarimetric sensor is based on a division-of-aperture approach and has a 640x512 InSb focal-plane array while the LWIR polarimetric sensor uses a spinning achromatic retarder to perform the polarimetric filtering and has a 324x256 microbolometer focal-plane array. The images used in this study include the S0 and S1 Stokes images of a scene containing a military vehicle and the natural background. In addition, relevant meteorological parameters measured during the test period include air temperature, ambient loading in the LWIR, relative humidity, and cloud cover, height and density. The data shows that the chief factors affecting polarimetric contrast in both wave-bands are the amount of thermal emission from the objects in the scene and the abundance of MidIR and LWIR sources in the optical background. In particular, it has been observed that the MidIR polarimetric contrast was positively correlated to the presence of MidIR sources in the optical background while the LWIR polarimetric contrast was negatively correlated to the presence of LWIR sources in the optical background.

7672-28, Session 7

Improved subsurface land mine recognition using high-boost fusion between passive Stokes vector imagery

A. M. El-Saba, Univ. of South Alabama (United States)

Detection and clearance of subsurface land mines has been one of the challenging humanitarian and military tasks. Passive polarization-based imagery has played important role achieving this task. This paper presents new fusion technique where polarization-based imagery is fused with traditional intensity imagery using high-boost approach. The main idea of the high-boost approach used in this paper is to give the polarization imagery obtained from the Stokes vector imagery more weight in forming the final fused image. It is shown that the proposed technique improve the recognition of surface land mines. This improvement is shown using the Receiver Operation Characteristic (ROC) curve approach.

7672-29, Poster Session

PolSAR image classification based on four-component scattering model and generalized linear regression model

Y. Ran, L. Kun, Q. Qin, Wuhan Univ. (China)

A classification method based on scattering model and generalized linear regression model for PolSAR image is proposed in this study. In this study, first of all, four-component target decomposition is implemented for PolSAR image. The derived four components are treated as four feature parameters, and then they are used as the inputs of generalized linear regression model. In the section of the generalized linear regression model, classification mathematical model is firstly established based on the theory of generalized linear regression, and then the model is solved by using the theory of least square method to derived its solution. The weighting coefficient of the four input feature parameters and the centers of each cluster are then obtained according to the solution of the generalized linear regression model. Weight map is calculated according to the four feature parameters and their weighting coefficients. Classify each pixel according to the weighting map and distance from pixel to cluster centers.

Compared with neural network, this method has the advantage of good stability and convergence, and lower time cost. Compared with bayes classification, this method does not need the probability distribution of the image. And compared with H-alpha-wishart classifier, this method has the flexibility to make a choice of number of classes.

Experimental results demonstrate the effectiveness of the new classification method for PolSAR image.

7672-30, Poster Session

Measuring birefringence in return-path mode and its application

M. I. Shribak, Marine Biological Lab. (United States)

We report development of various systems for measuring birefringence at normal reflection. Among them there are photometric, compensation, balance, interferometric, phase shifting, fiber optics techniques and devices. The systems could be used for singe-point or two-dimensional measurements. Owing to superposition of probe and return beams and double passing through a specimen, we would achieve: the better sensitivity; remote control can be realized if direct access to specimen is difficult; possibility to investigate polarization properties of lenses without immersion. Potential applications of the technique for remote polarimetric sensors that measure angular displacement, refractive index, temperature and inner stress will be described

7672-31, Poster Session

Adaptive Mueller polarimetry

S. N. Savenkov, National Taras Shevchenko Univ. of Kyiv (Ukraine)

The fact that in different problems the different elements of the Mueller matrix have different information values is known for a long time. Probably for the first time this fact was noted by F. Perrin as early as 1942. However, since that it was completely leaved out of account in polarimetric measurements.

The proper consideration of information value of whatever set of the Mueller matrix elements supposes both the dynamic modification of polarimeter characteristic matrix for measurement of the incomplete Mueller matrix containing these elements and the choice of respective variant of inverse problem solution basing on the set of measured matrix elements. These features present the essence of adaptive Mueller polarimetry. In this paper we consider realization of the adaptive Mueller polarimetry in scope of time-sequential measurement strategy.

7672-32, Poster Session

Synthetic Aperture Imaging Polarimeter (SAIP)

M. Roche, J. Vaden, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

No abstract available

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7673-01, Session 1

Development of a fieldable rapid pesticide exposure analysis sensing system

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Despite the recent interest in organically grown foods, most agricultural crops use multiple pesticides to optimize yield. There are many persons whose health may be affected by the spraying; there is the active applicator and the passive neighbors. In between these extremes are the farm workers who pick the crops anywhere from days to weeks after application. How much pesticide residue are these workers exposed to during a workday and how much is transferred back to the residence? Despite the low vapor pressures, what is the true concentration of pesticides surrounding a person when pesticides adsorbed to particulate matter are included? What is the relationship between the concentration around an individual and the amount adsorbed/ingested? To answer these questions on a statistically significant scale in actual field conditions, a portable, fast, inexpensive measurement device is required. We present herein results obtained using Surface-Enhanced Raman Spectroscopy (SERS) that demonstrate the capability to detect > 100 organophosphate, organochlorine and carbamate-based pesticides in the vapor phase as well as the ability of SERS sensors to detect a particular analyte in a synthetic urine matrix. We will also present data collected from CDC quantified urine samples and will present results obtained in a field test wherein SERS sensors wore worn as dosimeters in the field and real-time vapor sampling of the farm workers barracks was performed. The issue of potential interferences will also be discussed.

7673-02, Session 1

Metal-coated silicon nanopillars with large Raman enhancement for explosives detection

M. S. Schmidt, A. Boisen, Technical Univ. of Denmark (Denmark)

Surface enhanced Raman scattering (SERS) has been in the spotlight of the chemical and biological sensing community since its discovery. However, the lack of cost effective substrates which provide the necessary Raman enhancement has been a limiting factor in the deployment of mobile SERS based sensors.

In an effort to produce large areas of reproducible substrates with large Raman enhancement a novel fabrication method using standard cleanroom silicon processing equipment has been developed. These novel substrates display Raman enhancements on the order of 109 and over 100 times larger than commercially available substrates.

By narrow control of process parameters, freestanding high aspect ratio silicon nanopillars with vertical sidewalls and uniform heights are fabricated by maskless plasma etching known as the "black silicon method". To prevent contamination by fluorocarbons in the subsequent SERS spectra, the nanopillars are manufactured without the fluorocarbon passivation cycles used in the Bosch process. The nanopillar's height and density are tuneable and optimized for SERS. The nanopillars are coated with silver and/or gold to facilitate Raman enhancement. The coverage and surface roughness of the deposited metal layer have been optimized. Wafer scale surfaces, uniformly covered by 60 nm diameter silver coated nanopillars with aspect ratios of 10 and pillar densities of 25 pillars/µm2 show the largest enhancements of a wide variety of test molecules including Rhodamine 6G, thiophenol, isosafrole, trinitrotoluene and dinitrotoluene.

Under the framework of the Xsense project at DTU these low cost SERS substrates coupled with commercially available microspectrometers

(SERStech AB) will be included in handheld explosives detectors with applications in homeland security and landmine clearance.

7673-03, Session 1

Imprinted polymer particles labeled with quantum dots for detection of nitro-aromatic explosives

R. C. Stringer, S. Gangopadhyay, S. A. Grant, Univ. of Missouri-Columbia (United States)

The ability to detect high explosive compounds is a fundamental step in achieving the goal of creating devices capable of 'sniffing' out explosive devices. To detect high explosive compounds such as 2,4,6-trinitrotoluene (TNT), a molecularly imprinted polymer (MIP) sensor was developed. This sensor consists of amorphous MIP microparticles prepared using methacrylic acid as the functional monomer. The MIP microparticles are then combined with fluorescent semiconductor nanocrystals, or quantum dots, via a simple crosslinking procedure. To study the sensor's ability to detect nitroaromatic analytes, the fluorescent-labeled MIP particles were exposed to aqueous 2,4-dinitrotoluene (DNT), a nitroaromatic molecular very similar to TNT, as well as TNT itself. The preliminary data indicate that the sensor is capable of detecting nitroaromatic compounds in solution with high accuracy and specificity, achieving lower limits of detection of 30.1 µM and 40.7 µM for DNT and TNT, respectively. The detection mechanism also acted rapidly, with response times as fast as 1 minute for TNT. These results illustrate the potential application of the fluorescent-labeled MIP sensor for detecting high explosives, with the potential for future use in detecting vapors from explosive devices and in an array of environmental conditions.

7673-04, Session 1

Plasmonics nanostructures for SPR sensing and imaging

A. Dhawan, Duke Univ. (United States); M. Canva, Lab. Charles Fabry (France); T. Vo-Dinh, Duke Univ. (United States)

No abstract available

7673-05, Session 2

Infrared surface plasmon resonance biosensor

J. W. Cleary, R. E. Peale, Univ. of Central Florida (United States); W. R. Buchwald, Air Force Research Lab. (United States); O. J. Edwards, Zyberwear, Inc. (United States)

A Surface Plasmon Resonance (SPR) biosensor that operates deep into the infrared (3-11 µm wavelength) is potentially capable of biomolecule recognition based both on selective binding and on characteristic vibrational modes. A goal is to operate specifically at wavelengths where biological analytes are strongly differentiated by their IR absorption spectra and where the refractive index is increased by dispersion. This will provide enhanced sensitivity and selectivity, when biological analytes bind reversibly to biomolecular recognition elements attached to the sensor surface. Quantum cascade laser or IR LED as the source, a silicon prism, a sensor chip with doped silicon as the conducting surface, all-silicon microfluidic channels & controls, and an IR 2-D array detector

are proposed. In comparison to gold films, the usual surface plasmon host, the lower plasma frequency of doped silicon allows IR SPP fields to be confined to heights above the sensor surface of the order of 1 micron, so that there is good spatial overlap between fields and the biological analyte-ligand. Because the method works in the regime of total internal reflection, silicon allows exploitation of significantly larger index values for the sample of interest --up to 3.4-- than are useful conventionally in the near-IR with glass prisms (n ~1.5). Design calculations and preliminary experimental results are presented.

7673-06, Session 2

Label-free detection of biomolecules using a tapered optical fiber sensor

Y. Tian, W. Wang, A. Chery, Jr., N. Wu, C. Guthy, R. Liu, X. Wang, Univ. of Massachusetts Lowell (United States)

A tapered optical fiber sensor (TOFS) is a kind of optical fiber sensor that uses special geometries to measure properties of surrounding environments or samples using evanescent waves. This paper presents a fast, highly sensitive, and low-cost tapered optical fiber biosensor that, using a miniature sensing probe, enables the label-free direct detection of biomolecules. The sensor takes advantage of the interference effect between the fiber's first two modes along the taper waist region. This effect causes interference fringe in the transmission spectrum. Because of these sharp spectrum fringe signals, as well as a long biomolecule reaction region, the sensor is fast and highly sensitive. To better understand the influence of various biomolecules on the sensor, a computer simulation, which varied such bio-layer parameters as thickness and refractive index, was performed. The result of 0.4 nm/nm showed that the spectrum fringe shift of the sensor was large enough to be easily measured even when the bio-layer was nanometers thick. A tapered optical fiber biosensor was then fabricated and evaluated with an Immune globulin G (IgG) antibody-antigen pair, and showed good performance.

7673-07, Session 2

Chemical and biological sensors based on nanomembrane technology

O. Ebil, A. S. Sharkawy, E. J. Kelmelis, EM Photonics, Inc. (United States); M. J. Zablocki, D. W. Prather, Univ. of Delaware (United States)

There is a growing need for miniature low-cost chemical sensors in monitoring environmental conditions. Applications range from environmental pollution monitoring, industrial process control and homeland security threat detection to biomedical diagnostics. What is needed is an economical, compact, low power, light-weight sensor capable of accurately detecting chemical and biological hazards in real time. Integrated opto-electronic sensors can provide chemical & biological sensing by monitoring attachment induced changes in the refractive, absorptive, or luminescent properties of materials. Silicon nanomembrane technology can enable the fabrication of compact, replaceable/disposable and highly sensitive optoelectronic sensors for chemical and biological sensing. Silicon nanomembranes are single crystals of Si that have been released from SOI substrates and redeposited on foreign flexible or flat substrates enabling the best features of different materials. Although they are in fact single crystals and posses the electronic properties of bulk silicon, they are flexible, deformable, and conformable. Fabrication of 3D structures is also possible by multiple transfers and stacking of nanomembranes opening a wide variety of possible device designs and applications. Current opto-electronic sensors designs can be modified to take advantage of Silicon Nanomembrane technology. User replaceable/disposable active/passive sensing element(s) based on this technology can drastically improve the device sensitivity/accuracy and reduce the cost/power. In this study, we propose several chemical & biological sensor designs based on nanomembrane technology.

7673-08, Session 2

SERS molecular sentinel nanoprobes for biological sensing

H. Wang, T. Vo-Dinh, Duke Univ. (United States)

No abstract available

7673-09, Session 3

Autonomous radio-analytical platform for in-field monitoring of radionuclides in the aqueous environment

M. J. O'Hara, J. W. Grate, Pacific Northwest National Lab. (United States); S. R. Burge, Burge Environmental (United States)

Intentional and unintentional releases of radionuclides into the environment have occurred at government, industrial, and power-generating facilities throughout the world. In many cases, these spills or releases have resulted in the percolation of radioactive solutions through the vadose zone and into the underlying aquifer. Upon entry of these radionuclides into aquifers, uncontrolled migration away from the source of contamination begins to occur. At the Hanford Site, Washington, radioactive groundwater contamination plumes are a major concern, as an estimated 450 billion gallons of contaminated waste solutions were released to the ground during 50 years of nuclear weapons production.* Researchers at PNNL and Burge Environmental, Inc., are collaborating in the development of groundwater monitoring systems that are capable of autonomous operation in remote field locations. Individual radioanalytical modules have been developed in order to measure specific plume contaminants. The functionality and performance of these automated radioanalytical modules, including those for fission products 90Sr, 99Tc and 129I, as well as for uranium, will be discussed. Each module consists of a fluidic system that delivers sample either directly to a detector or concentrates the radionuclide prior to detection in order to achieve levels of quantification at or below challenging drinking water standards. These monitoring systems can be deployed at locations where frequent measurements are required to understand contaminant transport or to evaluate effectiveness of active remediation processes. The systems can acquire samples from wells or aquifer tubes at programmed time intervals, perform conventional water measurements (pH and conductivity), measure the radionuclide of interest, and communicate results to a remote user. *http://www.hanford.gov/cp/gpp/

7673-10, Session 3

Floating gate-based ultra-high-sensitivity two-terminal AlGaN/GaN HEMT hydrogen sensor

S. A. Eliza, A. K. Dutta, Banpil Photonics, Inc. (United States)

This paper presents the analytical performances of an AlGaN/GaN High Electron mobility Transistor (HEMT) based sensor for the detection of H2 and CO gases. The model calculates the changes in drain-to-source current and sensitivity of the device due to adsorbed atomic density of gases at the gate terminal. Simulated results indicate that AlGaN/GaN HEMT based floating gate sensors are highly suitable for the extreme environment detection of various gases with concentrations as low as ~ ppb level.

Due to presence of high mobility two-dimensional electron gas (2-DEG) closer to the heterointerface (~ 25 nm), AlGaN/GaN HEMTs are highly sensitive to any surface charge condition. Exploiting this property of the HEMT, AlGaN/GaN HEMT has been demonstrated for the detection of polar liquids, gases or biomolecules [1]. Analytical studies for AlGaN/GaN based Schottky diode sensors for the detection of hydrogen have been presented [2]. This paper presents the analytical characteristics of a

floating gate AlGaN/GaN HEMT as hydrogen sensors.

The selectivity of the device depends on the morphology of the catalytic gate metal. It has been reported that hydrogen is the only species which can diffuse through a continuous, nonporous Pt gate. The introduction of porosity would allow the absorption of other gaseous substances (hydrocarbons, CO etc.) as well as hydrogen. Hydrogen molecules dissociate on the Pt surface, forming atomic hydrogen and atomic hydrogen diffuses through the Pt layer, and reaches the Schottky interface, establishing an equilibrium atomic hydrogen concentration at the interface. The shift in Schottky barrier or threshold voltage of the HEMT can be explained due to the formation of the mono atomic dipole layer of hydrogen at the Pt/AlGaN interface [3]. The threshold voltage shift due to adsorption of hydrogen can be written as [3],

$$(1)$$

where p is the dipole moment, ni is the adsorbed interface density of atomic hydrogen and d is the permittivity of the dipole layer. The change in threshold voltage modulates the polarization induced 2-DEG density at the heterointerface in GaN as follows:

$$(2)$$

where is the polarization induced sheet charge density, b is the Schottky barrier height, EF is the Fermi energy at the interface relative to the GaN conduction-band-edge, ΔEC is the conduction band offset at the AlGaN/GaN interface, dd is the thickness of AlGaN layer, and Δd is the offset of the 2-DEG from the heterointerface. The drain current for the sheet carrier density can be obtained as,

$$(3)$$

Here v is the drift velocity due to the drain-to-source potential and Z is the gate width. Changes in current, ΔId and sensitivity ($\Delta Id/Id$) have been calculated based on the equations (1), (2), and (3) using the method described in [4]. The simulation results suggest highly sensitive (~ 1 ppb) and linear performances of the sensor.

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7673-11, Session 3

Investigations for real-time Raman measurements in the deep-ocean by applying a 1.5 W BA DFB diode laser and long optical fibers

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Raman spectroscopy is a powerful tool to obtain fingerprint" spectra from substances in numerous applications. In-situ and/or real time measurements are interesting for the detection of minerals, organic compounds, gas hydrates or methane in the deep-ocean. For such measurements, it is desirable to avoid complex and large Raman systems (laser, spectrometer, electronics, etc.) as underwater instrument. In this work, we demonstrate the possibility to send the laser light via an excitation fiber of at least 1000 meters to an easy movable tiny optode down to the deep-sea area of interest and to transmit the Raman scattered light back on board with a second fiber.

In a laboratory set-up a ridge waveguide (RW) or a broad area (BA) DFB-lasers with an internal grating were used, respectively. The RW device had a stripe width of 3 µm and a length of 1.5 mm. The reliable output power was 200 mW, the emission width is below 1 MHz with a side mode suppression ratio of 45 dB. The BA DFB with a stripe width of 50 µm has a broader spectral line width of about 0.6 nm still suitable for Raman spectroscopy and an output power up to 1.5 W.

After optical filtering to suppress the amplified spontaneous emission (ASE) of the lasers, 100 mW and 500 mW were coupled in the 100 µm low-OH fiber of 1000 m length (Fibertech). At the end of the 1000 m we obtain 32 mW and 200 mW, respectively, on the probes. The Raman scattered light was collected in the optode and via a second fiber transmitted back to a spectrograph (PI 320 with cooled CCD 256 x 1024 EHRB, PI). We could detect a Raman spectrum in 5 sec (RW laser) and in 1 sec (BA laser). Thus, real time measurements in the deep-ocean with detection times in the second range are realistic.

The measured spectra of minerals (sulphur, sulphates, carbonates, sulphides) will be presented for both excitation powers. Additionally, measurements on a methanol/water mixture to simulate methane will be discussed.

7673-12, Session 3

Steam distribution and energy delivery optimization using measurement and control over wireless sensors

J. Lake, G. O. Allgood, T. Kuruganti, Oak Ridge National Lab. (United States)

The Extreme Measurement Communications Center at Oak Ridge National Laboratory (ORNL) proposes to explore, based on existing technologies, the development of a real-time measurement-based energy efficiency optimization framework for steam distribution. We propose an integrated, holistic, system-level approach to optimize the energy flow within the steam distribution system. We are targeting significant achievable energy gains in steam lines through proper system integration and real-time monitoring and control. To assess the real-time steam distribution inside the steam line our framework will rely on real-time wireless sensor measurements. These sensors will provide data augmented by real time acoustic is algorithms for understanding the state of steam traps and energy losses and their locations within the system . A major enabling technology is the use of distributed sensors to capture the flow and temperature of the steam in the distribution network while assuring the pedigree of the data. The goal is to understand the feasibility of integrating electric distribution data, buildings data, and other sensors sources into a unified site-wide monitoring of energy generation, consumption, and waste management. The ultimate goal is to develop a platform technology the enables the extension of this implementation to include more than just steam traps and to make the approach transplantable to other DOE and non-DOE sites.

7673-13, Session 3

Taking the lab to the sample: real-time spectral monitoring

W. Yang, BaySpec, Inc. (United States)

Biomedical and analytical instrumentation professionals have long recognized great potential for longer wavelength excitation Raman spectroscopic analyzers in many application areas, ranging from lab analysis, to hospital bedside or portable field monitors. Until now, however, the longer wavelengths, i.e., excitation wavelengths beyond the typical 785nm or 810nm Raman instruments based on dispersive technology were virtually non-existed. This was due to the unavailability of practical components and technologies. Raman analytical instrumentation was too big, too expensive, too fragile, and so sophisticated they required highly trained operators for "real-world" applications use. Recent advances in high volume optical telecom device manufacturing; however, presents a disruptive new picture today.

7673-14, Session 4

Measurements of dual-excitation-wavelength fluorescence spectra for individual atmospheric particles

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We report dual-excitation-wavelength fluorescence spectral measurements of single atmospheric aerosol particles as they flow through an optical cell. For each particle, one spectrum is excited with light at 263 nm, and the other is excited with light at 351 nm [1].

In our earlier work we measured laser-induced fluorescence (LIF) spectra of individual atmospheric aerosol particles with our particle fluorescence spectrometer (PFS), and analyzed the spectra using an unstructured hierarchical cluster analysis. Measurements were made at Adelphi, MD, and at New Haven, CT and Las Cruces, NM [2]. The threshold of the distance metric (dot product between normalized spectra) used in the cluster analysis was chosen so that a high fraction (typically around 90%) of the LIF spectra fall into 8 to 10 clusters. The measurements were taken: a) with different instruments, b) at different times of year; and c) in regions with different climates. There are remarkable similarities among most of the primary clusters found at the three sites. The fraction of particles in each cluster, however, varies with time and regional climate. Fluorescent molecules in the atmosphere are almost exclusively organic carbon (OC) (including biological OC), and, in the great majority of cases are aromatic OC, e.g., polycyclic aromatic hydrocarbons (PAH), substituted PAH, and heterocyclic aromatics. Some of the clusters found at each site have spectra that are similar to spectra of some important classes of atmospheric aerosol, such as: a) bacteria and proteins (spectra dominated by tryptophan); b) marine aerosol; c) humic/fulvic materials, combustion aerosols and PAH, and humic-like substances (HULIS); and d) cellulose. On average, the broad spectra characteristic of some humic/fulvic acids, HULIS and some combustion aerosols comprise 28-43% of fluorescent particles at all three sites. Cellulose-like spectra contribute only 1-3%. Bacteria-like spectra comprise around 1-2% of the LIF spectra.

In the dual-excitation-wavelength spectral measurements made at New Haven, CT during January-April 2008 almost 6 million spectra were recorded. About 29% of particles had fluorescence above noise for 351-nm excitation. About 38% of particles had fluorescence above noise for 263-nm excitation, and of these about 10% (4% of total particles) had spectra with fluorescence similar to that of bacteria (peak emission around 350 nm). Of the 4% of total particles with bacteria-like spectra (263-nm excitation), about 30% had 351-nm-excited spectra that are clearly similar to bacteria. These measured spectra suggest that a dual-wavelength approach may provide a new diagnostic tool for better classifying biological and other organic-carbon atmospheric aerosols.

[1] Huang, Y.-L. Pan, S.C. Hill, R.G. Pinnick, R.K. Chang, "Real time Measurement of Dual Wavelength Laser-Induced Fluorescence Spectra of Individual Aerosol Particles," Optics Express, 16, 16523-16528, Oct. 13 (2008).

7673-15, Session 4

Detection of volatile analytes using an optical fiber-based reflectance sensor

D. J. Howard, X. Fan, J. Liu, Y. Sun, P. Whiteside, M. F. Almasri, Univ. of Missouri-Columbia (United States); G. C. Frye-Mason, A. Thompson, ICx Nomadics, Inc. (United States)

Fiber based sensors are very attractive due to their small size and simplicity in structure. Micro-Gas Chromatographers can utilize such structures in the form of end column detectors. These detectors have analytes that are deposited onto the surface and then removed by a carrier gas flow. By using a separation column multiple analytes can

easily be resolved. In this proceeding we report on a reflectance based fiber sensor that is capable of detecting volatile chemicals. This novel sensor has been coated with a metallic thin film. This film will reflect a portion of light that will be guided to a photodiode. The reflection from the metal will serve as a baseline and any analyte that adheres to the surface will change the refractive index and cause the intensity to change. In this proceeding we specifically target the analytes Trinitrotoluene (TNT) and Dinitrotoluene (DNT) for their obvious defense applications. This work could lead to a portable sensor capable of detecting low concentrations of TNT and other volatile chemicals.

7673-16, Session 4

Remote sensing from manned low Earth orbit spacecraft: implications for International Space Station

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This paper addresses the question of what contributions the International Space Station (ISS) can make as a sensor based remote sensing platform. There is precedent for the use of manned platforms in Low Earth Orbit (LEO). Skylab had the Earth Resources Experiment Package (EREP). In the Shuttle -Mir program, the Piroda module was dedicated to Earth sensing. One experiment in the Piroda, the Multispectral Stereo Scanner (MOMS-2P) was used to quantify the advantages of performing remote sensing on the ISS. The Space Shuttle program also made significant contributions to Earth observations. Sixteen missions carried electronic experiment packages for Earth observations and crew on almost every mission performed earth observations using cameras.

Experiments planned for the ISS can also tell us much about the potential the ISS has as a remote sensing platform by examining their design and objectives. In March of 2009 an experiment called Agricultural Camera (AgCam) was delivered to the ISS for installation in the window of the Laboratory module. In fall of 2009 two more remote sensing experiments arrived on the ISS - the Hyperspectral Imager for the Coastal Ocean (HICO) and the Remote Atmospheric and Ionospheric Detection System (RAIDS). These instruments will be combined on one experiment package, HICO- RAIDS experiment package (HREP), and will be placed outside the ISS, on an external platform. The ISS has the infrastructure to support Remote Sensing payloads and there are several external sites that are configured to support Remote Sensing.

7673-17, Session 4

Feasibility study of detection of hazardous aerosol pollutants using passive open-path FTIR

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Developing measurement abilities of hazardous atmospheric aerosols is important in terms of environmental monitoring, risk assessment and crisis management. Open-path infrared instruments have been identified as a possible powerful tool for such tasks. In recent years open-path FTIR systems (active and passive) have demonstrated great potential and success for monitoring air pollution, industrial stack emissions, and trace gas constituents in the atmosphere. However, the above studies were focused mainly on monitoring gaseous species and very few studies have investigated the feasibility of detecting bio-aerosols and dust by passive open-path FTIR measurements. The goal of the present study is to test the feasibility of detecting a cloud of toxic aerosols by a passive mode open-path FTIR. More specifically, we are focusing on the detection of toxic organophosphorous nerve agents for which we use Tri-2-ethyl-hexyl-phosphate as a model compound. We have determined the compounds' optical properties, which were needed for the radiative

calculations, using a procedure developed in our laboratory. In addition, measurements of the aerosol size distribution in an airborne cloud were performed, which provided the additional input required for the radiative transfer model. This allowed simulation of the radiance signal that would be measured by the FTIR instrument and hence estimation of the detection limit of such a cloud. We are currently conducting outdoor measurements of such clouds and the experimental results will be compared to the model calculations to asses the actual detection ability of the technique under various field conditions.

7673-18, Session 4

Standoff gas identification and quantification from turbulent stack plumes with an imaging Fourier-transform spectrometer

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Benefiting from the rich amount of spatial and spectral information provided by a hyperspectral imager such as an imaging Fourier-transform spectrometer (IFTS), we developed a suite of gas quantification algorithms that were applied to identify the gas released by distant stacks, and to quantify their specific mass flow rates. The method successfully performs the gas quantification through a range of important radiometric and instrumental considerations. Amongst them are the retrieval of atmospheric composition and the characterization of sky spectral radiance.

A Telops Hyper-Cam IFTS was used to collect the hyperspectral data (320 × 256 pixels) over the long wave infrared region (7.7 μm to 11.8 μm). The selected spectral range enables to properly quantify the main combustion products that are H_2O and CO_2. Secondary products can then be identified and their quantity estimated.

Finally interactions between the released gases and the fluctuating winds result in strong turbulences. The latter are accounted for by a recently developed algorithm avoiding scene change artifacts (SCA) which appear when the scene radiance is changing over the time of the acquisition of an interferogram. The novel approach, previously applied to turbojet exhausts, ensures valid estimation of the spectral radiance emitted by the plume.

7673-19, Session 4

Development of a colorimetric sensor array for detection of explosives in air

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Nowadays international terrorism turns to public concern appearing in various forms, situations and places. New technology must be developed to detect easily a variety of illegal chemicals, substances, drugs and explosives carrying by suspects as well as hidden in mails, luggage and vehicles. The technologies should be portable, rapid, highly sensitive, specific - minimizing false positives - and low cost.

In the framework of the larger research project 'Xsense' we are developing a simple colorimetric sensor array which can be useful in detection and identification of explosives like DNT and TNT in the presence of water vapour and volatile organic compounds (VOCs) in air. The technology relies on an array of dyes immobilized on a solid support. Upon exposure to the analyte in suspicion the dye array changes colour. Each chosen dye reacts chemoselectively with analytes of interest. A change in a colour signature indicates the presence of unknown explosives and VOCs.

We are working on the selection of dyes that undergo colour changes in the presence of explosives, as well as on the development of an

immobilisation method for the molecules. Digital imaging of the dye array before and after exposure to the analytes creates a colour difference map which creates a unique fingerprint for each explosive. Such sensing technology can be used to screen for relevant explosives in a complex background as well as to distinguish mixtures of VOCs distributed in gas phase. This sensor array is inexpensive, and can potentially be produced as single use disposables.

7673-20, Session 4

A region dynamic analyzing of land use and cover changing based on GIS and RS

M. Yu, Fujian Normal Univ. (China)

Regional difference of environmental evolvements is one of important aspects in world change research program (WCRP) , Changes in land cover and in the way people use the land have become recognized as important global environmental change in many areas. Land-use and cover changing (LUCC) is one of the major studies of global changing lately. Land-use is the term which covers the condition of used-land, the method, extent, structure, regional distributing and benefits in the land-use. It is affected by the natural condition or is enslaved to the conditions in society, economy and technology, and social production mode plays a decisive role in land-use; land-cover is the state of covering which is formed on account of the earth's surface or contrived by human being, is the summary of vegetation and artificially covering on the earth's surface. So land-use and cover changing is connecting closely. Land-use and cover changing information points that information on the position, distributing, range, and size of land-use and cover changing in the certain time. Motivated by a global concern for sustainability and environmental quality in city, a considerable number of studies have utilized satellite sensor data in the analysis of urban morphological change .some studies focused on the physical and socioeconomic drivers of change in urban land cover and implications on land use practices and resource management. Other studies went beyond the characterization of change and its causes and attempted to integrate remotely sensed data with models of urban growth to project future change. GIS and RS technologies are widely applied for LUCC studies providing a powerful tool for capturing, storing, checking manipulating, merging, analyzing and displaying data. Especially RS technology are also widely used for LUCC studies such as automatic discovery changing, automatic extraction changing area, confirmation changing type, using interactive explanation accessorily to extract the changing information of land-use in the research area. RS has an important contribution to make in the actual change in LUCC on regional. In this article we analyzed LUCC of studying area based on RS and GIS. And we discussed the drive of land-use and cover changing briefly. It is the reference meaning for the regional sustainable development.

7673-21, Session 5

Surface-enhanced Raman scattering on optical material fabricated by femtosecond laser

W. Wang, H. Huo, N. Wu, M. Shen, C. Guthy, X. Wang, Univ. of Massachusetts Lowell (United States)

Raman spectroscopy is a technology that can detect and distinguish materials based on the materials' Raman scattering. However, the signal produced using this technology is usually too small to be useful. The Raman spectrum signal can, however, be amplified by creating rough patches on the surface of a material. In this paper, a novel method to produce nanometer-sized features on optical materials such as glass, fused silica, and quartz substrate is presented. Using a femtosecond laser, the transparent materials are sputtered and redeposited producing structures with nano-features. Scanning electron microscope photos of nano-structures on quartz substrate and optical fiber show that features less with size of less than 100 nm have been successfully fabricated.

The 3D micro- and nano-structures of the sensor were studied using a confocal Raman spectrum microscope and focused ion-beam milling. Raman signals show that the intensity of the signal generated by Raman scattering was greatly enhanced compared to substrates without nano-features.

7673-22, Session 5

High-efficiency LWIR acousto-optic tunable filter (AOTF) imager

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We have developed AOTF based LWIR high efficiency imager and have taken data at room temperature. This paper will describe details of operation and results for chemical sensing.

We have developed and fabricated a Tl3AsSe3 (TAS) crystal based acousto-optic tunable filter (AOTF) for operation between the 8 to 12.0 μm wavelength regions. By improving the crystal quality, coating and fabrication we were able to improve significantly. We demonstrated peak efficiency greater than 60% with a 10.6 μm source and 2 watts of RF input power. This high efficiency should enable high resolution and large throuput for AOTF based imaging and spectroscopic systems.

7673-23, Session 5

Covert spectrally coded infrared paints for target tagging, tracking, and locating

G. M. Williams, Jr., Voxtel, Inc. (United States)

Voxtel's has developed and will present data on a set of fully calibrated taggants that were developed and demonstrated with a delivery, interrogation, and detection system capable of a standoff range of > 3.8 km in a field test.

- Remote sensing of taggants was first modeled and then demonstrated
- A commercial off the shelf laser interrogation and detection system was prototyped and demonstated
- Background fluorescence in the Visible/red was obtained
- Calibrated laboratory and field data was obtained

Voxtel has established the nanocrystal taggants, functionalized with luminophores, with well defined visible (VIS), near-infrared (NIR) and/or short-wavelength-infrared (SWIR) emission spectra, allowing detection with silicon cameras, night vision goggles (NVGs), and/or SWIR InGaAs cameras, depending on the taggant chosen.

The nanoparticles were based on nanocrystal quantum dots (NQDs), which Voxtel has developed to be dispersed in ink, paint, solvents, or aerosol cans. Voxtel has demonstrated detection of these NQDs at ranges exceeding 3.8 km with laser interrogation.

Using colloidal chemistry processes, Voxtel has manufactured a variety of NC materials, including ZnO, ZnS, YVO4, CdSe, CdS, CdTe, InP, InAs, PbSe, and PbS. The size and the shape of these NQDs, as well as their dopants, determine the emission characteristics.

Upon interrogation with a laser, the taggants emit at one or several wavelengths, each with different intensity in multiple bands of the VIS-SWIR region, allowing deployment of coded binary taggants. Detection ranges have been demonstrated against a variety of simulated backgrounds (cement, fabric, paint, wood, etc.). Based on similar experiments, it is believed that these taggants can be detected from airborne and space platforms as well.

The taggants have been shown to be deployable in solvents, inks/paints, and aerosols.

Low-cost methods of manufacturing the taggants at $1/g in multi-kilogram quantities have been developed and prototyped. We estimate that 0.25 g/m2 coverage is required for adequate tagging.

7673-24, Session 5

Shifted excitation resonance Raman difference spectroscopy using a microsystem light source at 488 nm

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Compact mobile sensor systems using contactless spectroscopic methods for the in situ detection become more and more important, e.g. in medicine or for food analysis. Raman spectroscopy is a well-established method for qualitative and quantitative analysis. The resonance Raman effect at excitation wavelengths in the visible spectral range such as 488 nm can enhance the Raman signals by several orders of magnitude suitable for trace detection in the low concentration range. Nevertheless a fluorescence background can mask the Raman signals of biological samples. Shifted excitation Raman difference spectroscopy (SERDS) is well suited to recover the Raman signals from fluorescence or background noise.

In this paper experimental results in shifted excitation resonance Raman spectroscopy (SERRDS) at 488 nm will be presented. A novel compact diode laser system was used as an excitation light source. The device is based on a distributed feedback (DFB) diode laser as a pump light source and a nonlinear frequency doubling using a periodically pooled lithium niobate (PPLN) waveguide crystal. All elements including microoptics are fixed on a micro-optical bench with a footprint of (25 x 5) mm2. A combined temperature management of the DFB laser and the crystal was used for wavelength tuning. The second harmonic generation (SHG) provides an additional suppression of the spontaneous emission and no laser bandpass filter was used for the Raman experiments.

Raman and SERRDS spectra excited at 488 nm for selected samples e.g. food colorants and meat will be presented to demonstrate the suitability of this light source.

7673-25, Session 6

Rational engineering of highly sensitive SERS substrate based on nanocone structures

Z. Li, M. Hu, W. Wu, F. Ou, R. S. Williams, Hewlett-Packard Labs. (United States)

At last meeting, we reported a new type of surface-enhanced Raman Spectroscopy (SERS) substrates based on metal (Au or Ag) coated Si nanocones fabricated by a Bosch etching process. The substrate showed reliable SERS performance with an analytical enhancement factor greater than 10e7. However, the process is limited to single crystalline silicon material, also silicon can absorb both incident and scattered light, making it difficult to investigate the SERS enhancement mechanism. To further improve the sensitivity of the SERS substrate, we have recently developed a process to duplicate the Si nanocones by a cross-linked polymer using 3-D nanoimprint lithography (NIL). The SERS substrate made by NIL demonstrated better enhancement factors for both 633 nm excitation and 785 nm excitation, with a notable performance improvement of a factor of 10 at 785 nm excitation. We will report the rational engineering of the nanocone based SERS substrate and the fundamental understanding of the enhancement mechanism.

7673-26, Session 6

Wireless organic optical polymer sensor based on planar waveguide

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Wang, Alabama A&M Univ. (United States)

We describe a novel sensor of ammonia based on a planar optical waveguide made of thin film of polymer polyimide doped with indicator dye bromocresol purple. Ammonia is a caustic gas that in high concentrations will damage the lungs of humans and even kill. However, the main purpose is to place an ammonia sensor in a chicken house to reduce losses. The film of dye-doped polyimide demonstrated reversible increase of absorption with a peak near 600 nm in response to presence of ammonia in ambient air. Coupling of input and output optic fibers with the waveguide was done by means of coupling prisms or coupling grooves. The latter configuration has the advantage of low cost, less sensitivity to temperature variation, and the possibility of coupling from both sides of the waveguide. A special experimental setup was built to test the sensor. It included test gas chamber with sealed optic fiber feed-throughs, gas filling line, laser source, photodetector, and signal processing hardware and software. Overexposure of the sensor to more than 5000 ppm of ammonia led to the saturation of the sensitive film and, as a result, significant decrease of its sensitivity and increase of the response time. The prototype Govindratm 006X wireless gas sensor has been developed and tested.

7673-27, Session 6

UV imaging of biochips based on resonant grating

J. Reverchon, K. Robin, Thales Research & Technology (France); H. Benisty, Institut d'Optique Graduate School (France); M. Fromant, P. Plateau, Ecole Polytechnique (France)

In the frame of biological threat, security systems require label free biochips for rapid detection. Biosensors enables to detect biological interactions, between probes localized at the surface of a chip, and targets present in the sample solution. Here, we present an optical transduction, enabling 2D imaging, and consequently parallel detection of several reactions. It is based on the absorption of biological molecules in the UV domain. Thus, it is based on an intrinsic property of biological molecules and does not require any labelling of the biological molecules. DNA and proteins absorb UV light at 260 and 280 nm respectively. Sensitivity is a major requirement of biosensing devices. Configurations leading to enhancement of the interaction between light and biological molecules are of interest. For a better sensitivity, resonant grating structures are then studied. They enable to confine the electric field close to the biological layer. Imaging of resonant grating is not largely studied, even for visible wavelengths, but it results in good sensitivity. The protein used in this study is the methionyl-tRNA synthetase. Its absorption is representative of protein absorption, and it can then serve as a model for immunological detection. The best experimental contrast due to a monolayer of proteins is 40%. With data processing currently employed for biochip imaging: average on several acquisitions and on all the pixels imaging the biological spots, the device is able to detect a surface density of proteins in the 10 pg/mm range. Instrumental resolution and spatial extent of the mode are discussed.

7673-28, Session 6

Piezo-impedance sensors to monitor degradation of biological structure

V. G. M. Annamdas, Nanyang Technological Univ. (Singapore); K. K. K. Annamdas, Univ. of Miami (United States)

Degradation of structure is an important phenomenon to be studied especially if the structures are made of wood. In countries like Japan, where timber structures are common and have to be protected against rain, sea water etc. The sea water or any acid attack on the wooden structure results in slow or rapid increase of moisture content in the wood which further results in degradation of the structure. Irrespective of the material type, ageing and deterioration are the key issues which dampen the life of any structure. This is especially true for green materials like

bamboo or timber. Thus, many structural Health monitoring (SHM) techniques have emerged to monitor the condition of structure to find out instability/deterioration issues at earlier stage of occurrence. In the recent past Piezoceramic transducers (PZTs) based electromechanical Impedance (EMI) technique has emerged as one of the feasible SHM technique which is simple but robust to detect variations in structures. These PZTs are usually surface mounted on the host structure to be monitored and are subjected to unit sinusoidal electric filed. This results in unique health signature, which changes as a result of any discrepancy in the host structural properties. In the present paper, PZTs are bonded on wooden samples; changes in the properties in wood due to disintegration in presence of acid or moisture are evaluated. This paper is expected to be a very useful for monitoring of any green material.

7673-38, Poster Session

Reversible low-loss fiber optic hydrazine sensor

A. Andrawis, B. Ranjitkar, X. Yan, Y. Peng, South Dakota State Univ. (United States)

No abstract available

7673-30, Poster Session

Assessment of multi-wavelength extinction using combined VIS-NIR-MIR measurements as a means of separating aerosol types

C. M. Gan, The City College of New York (United States) and The Graduate Ctr. (United States); P. A. Corrigan, B. M. Gross, F. Moshary, S. A. Ahmed, G. Bouton, The City College of New York (United States)

Indentifying and quantifying ambient aerosols are very important for air-quality applications. Unlike trace gases where chemical spectral signatures are very sharp and well defined, aerosol spectral signatures are broader and highly overlapping. Therefore separation of aerosols into broad species classes requires very broad spectral coverage from the visible (VIS) to mid-infrared (MIR). In particular, it would be useful to separate aerosols by species including sulphate-nitrates, organics and salts. It is reasonable to believe that optical extinction data in the MIR coupled with existing measurements in the VIS and near-infrared (NIR) should be able to distinguish these modes better. We assess the utility of such a MIR measurement from a suitable Quantum Cascade Laser (QCL) system when combined with a similar extinction measurement in the VIS and NIR using inexpensive compact sources. Based on realistic source characteristics, we study the information content in the spectral extinction using different combinations of extinction measurements using Least Squares Minimization applied to a wide range of aerosol multimode mixtures obtained using realistic aerosol models obtained from the Optical Properties of Aerosol and Clouds (OPAC) model. This model is especially convenient since the optical spectral extinction and backscatter spectra are evaluated over a wide wavelength range from 250nm to 40µm. In particular, we find that retrieval accuracy of the different components is dramatically improved with the addition of MIR extinction measurements at 5.2µm. Furthermore, we explore the sensitivity of the measurements to Relative Humidity (RH) and discuss suitable experimental methods to apply these measurements.

7673-31, Poster Session

Development of a high-speed real-time PCR system for rapid and precise nucleotide recognition

H. Terazono, Kanagawa Academy of Science and Technology (Japan); H. Takei, Kanagawa Academy of Science and Technology (Japan) and Toyo Univ. (Japan); A. Hattori, On-chip Cellomics Consortium Co., Ltd. (Japan); K. Yasuda, Tokyo Medical and Dental Univ. (Japan) and Kanagawa Academy of Science and Technology (Japan)

Polymerase chain reaction (PCR) is a common method used to create copies of a specific target region of a DNA sequence and to produce large quantities of DNA. A few DNA molecules, which act as templates, are rapidly amplified by PCR into many billions of copies. PCR is a key technology in genome-based biological analysis, revolutionizing many life science fields such as medical diagnostics, food safety monitoring, and countermeasures against bioterrorism. Thus, many applications have been developed with a thermal cycling. For these PCR applications, one of the most important key factors is reduction in the data acquisition time. To reduce the acquisition time, it is necessary to decrease the temperature transition time between the high and low limits of temperature as fast as possible.

We have developed a novel rapid real-time PCR system based on rapid exchange of media at different temperatures. This system consists of two thermal regulators and a reaction chamber for PCR observation.

As results, the temperature transition was achieved within 0.3 sec and the thermal stability was maintained during thermal cycling with rapid exchange of circulating media. This system allows rigorous optimization of the temperatures required for each stage of the PCR processes.

The amplicons were confirmed by electrophoresis. Using the system, rapid DNA amplification was accomplished within 3.5 min, including the initial heating and complete 50 PCR cycles.

These results indicate that the device could allow us faster temperature switching than the conventional conduction-based heating systems based on peltier heating/cooling.

7673-32, Poster Session

Impedance-based sensor technology to monitor stiffness of biological structures

K. K. K. Annamdas, Univ. of Miami (United States); V. G. M. Annamdas, Nanyang Technological Univ. (Singapore)

Metals and its alloys are the general engineering materials used in construction of any military or civil structures. However, recycling and timber products have also been in use for rehabilitation especially during epidemic of diseases or war or earthquake. Irrespective of the material type, ageing and deterioration are the key issues which dampen the life of any structure. This is especially true for green materials like bamboo or timber. Thus, many structural Health monitoring (SHM) techniques have emerged to monitor the condition of structure to find out instability/ deterioration issues at earlier stage of occurrence. In the recent past Piezoceramic transducers (PZTs) based electromechanical Impedance (EMI) technique has emerged as one of the feasible SHM technique which is simple but robust to detect variations in structures. These PZTs are usually surface mounted on the host structure to be monitored and are subjected to unit sinusoidal electric filed. This results in unique health signature, which changes as a result of any discrepancy in the host structural properties In this study, piezo impedance sensor is bonded on wooden sample, which is used to study changes in the properties of wood. Nails were fixed at different locations on sample to stiffen the structure gradually. The increase in stiffness is measured using the sensor. Such sensor system was previously employed for metals but this study found that they are equally capable for wood. This paper is expected to be a very useful for monitoring of any green material.

7673-33, Poster Session

A-vitamin photocurrent spectroscopy to thin film semiconductors apply

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We have obtained and characterized A-vitamin to be used as optical implant to a person who lost optical sensibility. After a short review of the required optical properties for this type of application, a detailed description of the production process and of the characterization experimental techniques is reported. The optics and electrical properties of A-vitamin films obtained with a Sol-Gel technical are presented in this contribution. These thin films were obtained on a glass substrate at room temperature. Optical absorption and current-voltage characterization for a varying doping level showed that the optical and electrical properties of these films are better than those of films obtained by other techniques. Specifically, the occurrence of a well-defined peak for the A-vitamin/ chlorophyll bond as well as reasonable values for both the electrical conductivity and activation energy were observed. The tradeoff between optical absorption and current of the membrane is discussed and conveniently parameterized in view of a complete detector optimization.

7673-34, Poster Session

Preparation and properties of new complex sensing film for fiber optic glucose sensor

J. Huang, C. Wang, Y. Yuan, H. Wang, L. Ding, D. Fan, Wuhan Univ. of Technology (China)

The detection of glucose concentration in blood is of great significance for monitoring human health and early diagnosis of diseases. Fiber optic biosensor based on enzyme catalysis is an effective way to determine glucose concentration. The research on high-performance optical sensing materials is the key technology to develop the fiber optic biosensors with good properties. The reported sensing materials for fiber optic biosensor based on enzyme catalysis usually consist of optical sensing part and catalysis part, the enzyme catalysis effect needs to transmit over long distance to arrive the optical sensing part, which will cause the sensor to have low response rate and poor properties.

In this paper, a new complex sensing film containing both optical indicator and enzyme(GOD) was prepared and its sensing properties were studied, using cellulose acetate(CA) as the carrier and tris(2,2'-blpyridyl)dlchloro-ruthenium (II) hexahydrate (Ru(bpy)3Cl2) as the indicator. The cross-linking method was used to immobilize the enzyme. The Leakage of fluorescence indicator in CA film is mainly related with the evaporation rate and the amount of CA and acetone. The factors such as activation condition, immobilization time to the enzyme activity of the sensing materials have been studied. The influence of temperature and pH value to the catalytic properties of the sensing film have also been investigated. The fiber optic glucose sensor with this complex sensing film was fabricated and its properties have been studied. The results show that this sensor has good performance with the detecting range of 100-600 mg/dL and fast response.

7673-35, Poster Session

Fiber optic sensor system for simultaneous measurement of different environmental parameters

L. Men, P. Lu, Q. Chen, Memorial Univ. of Newfoundland (Canada)

In-situ monitoring of physical, chemical, and biological parameters is of great importance for environmental, industrial, and biological applications. Among different parameters, measurement of salinity, saccharinity and temperature, especially simultaneous measurement of these parameters, is highly preferred for realizing measurement systems with high degree of integration and low-cost. In this paper, we report simultaneous salinity/saccharinity and temperature measurement with a fiber Bragg grating (FBG)-based sensor system. FBG sensors, which are microstructured fibers inscribed with periodic changes in the refractive index along the axis of the fiber, offer high sensitivity, and more importantly, the measurand-induced modulation is over an absolute parameter, i.e., wavelength. In order to achieve in-situ measurement, by adopting multiplexing technique, our sensor system consists of two FBG sensing elements in which one FBG is sensitive to salinity/saccharinity while the other one sensitive to temperature only. Experiments indicated that the salinity, saccharinity, and temperature sensitivities of the polyimide-coated grating were 0.0165 nm/M (blueshift), 0.0012 nm/°Bx (blueshift), and 0.0094 nm/°C (redshift), respectively. The temperature sensitivity of the acrylate-coated FBG is 0.0102 nm/°C (redshift). Our experiments showed that no crosstalk existed between these two sensing elements. Since the sensing elements have been integrated on one standard single-mode telecommunication fiber (Corning SMF-28), it is possible to achieve quasi-distributed in-situ measurement of salinity/saccharinity and temperature over a long distance. The technique offers a possibility to measure other parameters from the different responses of the gratings once a calibration curve is developed.

7673-36, Poster Session

A novel fiber optic biosensor for the determination of nitric oxide based on vicinal diaminobenzozcridine fluorescent probe

L. Ding, L. Huang, J. Huang, D. Fan, Wuhan Univ. of Technology (China)

Nitric oxide (NO) plays an important role in human physiology as an intra- and extracellular messenger molecule. It is widely involved in the process of cardiovascular, nervous, and immune systems, which would cause cardiopathy, diabetes, cancer, obesity and other diseases if NO is excessive or inadequate. Therefore, achieving for rapid and accurate detection of NO in the biological body is of great significance. In recent years, a large number of fluorescence probes have been developed to detect NO in tissues due to their high sensitivity, real-time detection, and simple measurement. However, most of them are obtained not rationally but empirically. With high sensitivity, fast signal transmission, excellent environmental adaptability and easy to be miniaturization, fiber optic sensor now represents the trends of a new generation of sensors. Fiber optic NO biosensors are the most promising detection method for realizing the real-time measurement of NO in vivo and in vitro, which attracts many scientists' attention.

In this work, a novel fiber optic biosensor for the determination of nitric oxide based on vicinal diaminobenzozcridine (VDABA) fluorescent probe was designed and fabricated. VDABA is a kind of fluorescence enhanced NO-sensitive material, and has been applied to the determination of NO in the human serum. We prepared a new complex sensing film containing both VDABA and cellulose acetate (CA) and studied its sensing properties. The leakage of fluorescence indicator in CA film was mainly related with the evaporation rate and the amount of CA and acetone. We also investigated the properties of this NO fiber optic biosensor during conditions of varied temperature, pH, and other specific interference factors. By means of the lock-in technology, the change of

fluorescence phase delay of the sensing film was detected, which had linear relationship with the NO concentration, and its detecting range was $30\times10-6$ to $60\times10-6$ M. The results showed that this NO-sensitive fluorescence fiber optic sensor may has the potential for use in real-time monitoring of NO concentration in vivo.

7673-37, Poster Session

Multifunctional sol-gel sensitive membrane for fiber optic biosensor

H. Wang, J. Huang, Y. Yuan, L. Ding, D. Fan, Wuhan Univ. of Technology (China)

The sol-gel technique is often used for the encapsulation of bioactive enzymes, in the development of sensitive membrane for biosensors. However, gelation process stresses and small gel pore size can result in a high mass-transfer resistance of biosensor, because of the long diffusion distance and the inaccessibility of substrate to the embedded enzyme. The immobilization method can affect enzymatic biocatalytic activities and can lower response rate of biosensor. The purpose of this work is to improve the performance of sensitive membrane.

In this paper, tetraethoxysilane was used as precursor in the experiment. The technique conditions for the suitability of silica membrane based on sol-gel method were studied. Then it was spun on pretreated substrate to form the Ru(bpy)3Cl2-containing silica membranes. Amino groups were produced on silica membrane surface using agent 3-aminopropyltriethoxy silane. Glucose oxidase was immobilized on aminated silica membrane by cross-linking agent glutaraldehyde. The immobilized enzyme in the new membrane was found to have high catalytic capability and good stability.

The optical biosensitive membrane was assembled on the sensor head. The lock-in phase amplifying technology based on fluorescence quenching by oxygen was used to detect the solutions with different glucose concentration. The response time of the sensor was less than 30s and the range for detecting of glucose concentration was 100 to 700 mg/dl. It demonstrated that this biosensor with the multifunctional sensitive membranes has high sensitivity, fast response and good stability.

Conference 7674: Smart Biomedical and Physiological Sensor Technologies VII

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Smart Biomedical and Physiological Sensor Technologies VII

7674-01, Session 1

Development of SAM-based multilayer SERS substrates for intracellular analyses

C. K. Klutse, B. M. Cullum, Univ. of Maryland, Baltimore County (United States)

Surface-enhanced Raman scattering (SERS) is a powerful tool for intracellular analyses due its minimally invasive nature and molecular specificity. This research focuses on optimizing the sensitivity of SERS in order to widely apply it to the detection of ultra-trace amounts of biomolecules within individual living cells. Recent results have shown that large SERS enhancement factors (EF) can be achieved with multi-layered SERS substrates. To fabricate multi-layer SERS substrates, alternating layers of metal films and metal oxide dielectric spacers are cast over a non-confluent monolayer of nanostructures. Individual particles of these substrates are then immobilized with antibodies to develop SERS-based immuno-nanosensors.

The multi-layer SERS EFs can be increased by the use of appropriate dielectric spacer to fabricate the substrates. To further understand the effect of dielectric spacers on the multi-layer SERS EFs, this talk discusses the characterization of the SERS EFs of multi-layer metal film on nanostructure SERS substrates fabricated with self-assembled monolayer (SAM) spacers. Monolayers of mercaptoalkanoic acids with different chain lengths have been systematically sandwiched between layers of metal films. It was found that the SERS EFs depend on the carbon chain length of the SAM. Also, evaluation of the nature of solvent used in monolayers formation showed marked effects on the SERS EFs. Using optimal SAMs and the appropriate solvent for SAM deposition, multi-layer SERS EFs an order of magnitude greater than optimized single layer SERS substrates were achieved. This talk will also explore the functionalization of the SERS substrates with appropriate bio-recognition elements to develop SERS-based immuno-nanosensors.

7674-02, Session 1

Semiconductor CdS:Mn/ZnS quantum dots for sensing applications

S. Santra, Univ. of Florida (United States)

Since past several years, quantum dot (Qdot) nanotechnology has advanced our capabilities towards sensitive and reliable imaging of biological specimens such as cells, tissues etc. It is well understood that surface passivation is extremely important in obtaining bright and photostable Qdots. Traditionally, an inorganic wide band-gap epitaxially-matched shell material (such as ZnS, ZnSe etc.) is used over the Qdot core (such as CdS, CdSe etc.). Surface passivation minimizes surface related defects and improves quantum efficiency as well as photostability. This is also applicable to dopant based Qdots such as CdS:Mn/ZnS Qdots. In this talk, I will present our research data on CdS:Mn/ZnS Qdots that are further surface modified with appropriate organic ligands for selective sensing applications. These ligands are capable of quenching Qdot luminescence via electron transfer process. Qdot luminescence is restored when electron transfer process is stopped. Using this quenching mechanism, we have demonstrated selective sensing of cadmium ions and glutathione in a highly sensitive manner. The Qdot probe for the selective detection of Cd2+ was developed by modifying the Qdot surface with the Cd ion selective ligand via a zero length coupling chemistry. The detection is based on an electron transfer process between the Qdot and the ligand, and subsequent blocking of the electron transfer pathways upon exposure to Cd2+. Similarly, we have developed a highly sensitive activatable Qdot probe for the detection of glutathione at physiologically relevant concentration range (1 to 15 mM).

7674-03, Session 1

Gadolinium-labeled dendronized gold nanoparticles as new targeted MRI contrast agent

H. Pan, M. F. Daniel, Univ. of Maryland, Baltimore County (United States)

Early diagnosis is critical for positive outcome of cancer treatments. In many cases, lives would be saved if the tumor could be detected at a very early stage. Nanoparticles have the property of passively targeting tumor sites due to their enhanced permeation and retention (EPR) effect. Thus they can play a critical role in improving the ability to find cancer in its earliest and most treatable stages. Furthermore magnetic resonance imaging is one of the most precise techniques for cancer screening since it can show 3D images of the tumors. For a better enhancement of the sensitivity of this method, MRI contrast agent (DOTA)Gd was attached to poly(propylene imine) dendrons of third generation and the obtained dendrons were used for modification of gold nanoparticles. The MRI contrast properties of these new dendronized gold particles were then investigated.

7674-04, Session 1

Using llama derived single domain antibodies to target botulinum A neurotoxins

M. D. Swain, E. R. Goldman, G. P. Anderson, U.S. Naval Research Lab. (United States); R. D. Bernstein, Nova Research, Inc. (United States); J. L. Liu, U.S. Naval Research Lab. (United States)

Llama serum contains both conventional IgG as well as unique forms of antibody that contain only heavy chains where antigen binding is mediated through a single variable domain. These variable domains can be expressed recombinantly and are referred to as single domain antibodies (sdAb). SdAb are among the smallest known naturally derived antigen binding fragments. They possess good solubility, thermal stability, and can refold after heat and chemical denaturation. Libraries derived from immunized llamas have been constructed and panned on BoNT A toxoid and A complex toxoid. Phage displayed binders were initially screened, moved to a protein expression vector and soluble sdAb was produced. Using a Luminex flow cytometer binders were evaluated in both direct binding and sandwich assays. Surface plasmon resonance studies using a ProteON XPR36 protein interaction array system gave information on binding kinetics and thermal stability after heat treatment was evaluated by Luminex. We have exploited the unique properties of sdAb and used them as biological recognition elements in immuno-based sensors that detect botulinum neurotoxin A.

7674-05, Session 1

Novel probes for visualizing reactive oxygen species in lipid membranes

G. Cosa, K. Krumova, McGill Univ. (Canada)

We are pioneering the preparation of lipophilic probes for the specific imaging of ROS in the membrane of live cells. Our strategy involves synthesizing a two segment receptor-reporter type free radical scavenger-fluorophore probe (an off-on fluorescent antioxidant indicator). The receptor segment in the probe mimics the structure and activity of the naturally occurring antioxidant -tocopherol. A covalently tethered

bodipy fluorophore serves the purpose of reporting, via emission enhancement, structural changes at the receptor end which result from the radical scavenging activity of the receptor. Herein we will describe our most recent results involving the preparation of a second generation of probes relying on newly synthesized bodipy dyes with better redox properties which lead to a 10 fold improvement in sensitivity compared to the originally published probe B-TOH. The new probes display up to 100 fold enhancement upon reaction with peroxyl radicals. We will describe the photophysical characterization of the new probes and address reactivity studies performed both at the ensemble and at the single molecule level and illustrating how lipid content affects the peroxyl radical scavenging properties of these newly developed fluorescent antioxidant indicators. Finally, cell studies will be briefly described.

7674-06, Session 2

Frequency domain fluorescence lifetime microwell-plate platform for respirometry measurements

M. R. Chatni, G. Yale, Purdue Univ. (United States); A. Van Ryckeghem, Insects Limited, Inc. (United States); D. M. Porterfield, Purdue Univ. (United States)

Traditionally well-plate based platforms used in biology utilize fluorescence intensity based methods to measure processes of biological relevance. However fluorescence intensity measurements suffer from calibration drift due to variety of factors. Photobleaching and self-quenching of the fluorescent dye causes the intensity signal to drop over the lifetime of the sensor immobilized in the well. Variation in turbidity of the sample during the course of the measurement affects the measured fluorescence intensity. In comparison, fluorescence lifetime measurements are not significantly affected by these factors because fluorescence lifetime is a physico-chemical property of the fluorescent dye. Reliable and inexpensive frequency domain fluorescence lifetime instrumentation platforms are possible because the greater tolerance for optical alignment, and because they can be performed using inexpensive light sources such as LEDs. In this paper we report the development of a frequency domain fluorescence lifetime well-plate platform utilizing an oxygen sensitive transition-metal ligand complex fluorophore with a lifetime in the microsecond range. The fluorescence lifetime dye is incorporated in a sol-gel matrix and immobilized on the base of micro-well of a 60 well micro-well plate. Respiration measurements are performed in both aqueous and non-aqueous environment. Respirometry measurements were recorded from single Daphnia magna egg in hard water. Daphnia is an aquatic organism, important in environmental toxicology as a standard bioassay and early warning indicator for water quality monitoring. Also respirometry measurements were recorded from Trisbolium castaneum eggs, which are common pests in the processed flour industry. Individual Trisbolium eggs were maintained in a gaseous atmosphere, matching that expected in an industrial fumigation, and respiratory behavior was measured during application of various fumigations used for pest management in agriculture.

7674-07, Session 2

NanoDLSay: a new platform technology for biomolecular detection and analysis using gold nanoparticle probes coupled with dynamic light scattering

Q. Huo, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Analytical tools for biomolecular detection and interaction study are critical for biomolecular research. An ideal analytical technique should meet a well known 4-S rule: have high Sensitivity, high Specificity, is Simple to use, and uses a Small volume of samples. However, techniques that meet all these criteria are very rare. Based on the unique optical property of gold nanoparticles, we recently developed a low cost, highly sensitive and extremely easy-to-use analytical technique, NanoDLSay, for biomolecular detection and analysis. Gold nanoparticles scatter light strongly at or near their surface plasmon resonance wavelength region, and can be detected by DLS with extremely high sensitivity. To conduct a biomolecular assay, a layer of "baiting" protein is conjugated to gold nanoparticles to form a light scattering probe. When target proteins bind to the nanoparticle surface through specific interactions, this will cause nanoparticle size increase or nanoparticle aggregation. Such a particle size increase or particle aggregation can be easily measured by dynamic light scattering (DLS), and correlated to analyte concentration. So far we have demonstrated that NanoDLSay can be used for numerous applications including: (1) Direct monitoring of gold nanoparticle bioconjugation process, characterizing the GNP bioconjugate quality and stability; (2) In situ monitoring and study of protein-protein interaction; (3) Immunoassay for protein biomarker detection; (4) DNA detection; (5) Monoclonal antibody isotyping, quality and affinity analysis. NanoDLSay has the potential to become a very powerful analytical techniques for biomolecular detection, analysis and interaction study.

7674-08, Session 2

Differential laser-induced perturbation spectroscopy: a novel approach to biosensing

D. W. Hahn, K. D. Buchanan, S. E. Smith, B. S. Sorg, Univ. of Florida (United States)

The development of new smart sensing methodologies that provide improved sensitivity and/or specificity for rapid and accurate biosensing is highly desirable for in situ and in vivo cancer screening and detection of biological pathogens. However, to date clinical applications of cancer sensing schemes have been for the most part limited by the large patient-to-patient variations in optical response (e.g. fluorescence or Raman signals), as well as by the large variation in background signal levels. A novel biosensing scheme is presented that holds promise to significantly enhance both sensitivity and specificity as compared to the current state-of-the-art optical-based sensing methodologies. This scheme is based on our recent research showing that the biological matrix may be altered by low intensity (i.e., below the ablation threshold) ultraviolet radiation (primarily 193 to 213 nm) such that the intrinsic fluorescence or Raman scattering response is perturbed. We propose a novel sequential combination of optical probing (for example by Raman or fluorescence), UV photochemical perturbation, and repeat optical probing to realize a powerful new spectral dimension based on difference spectroscopy that will be strongly coupled to the local biomolecular matrix. Since the same targeted material is optically probed both before and after perturbation with the UV light source, the resulting differential response can avoid the major limitation of the current biosensing schemes, namely, the significant variations in the absolute optical response, as generally observed in patient-to-patient populations. Preliminary data will be presented for a range of organic and biological materials.

7674-09, Session 2

Chemically responsive hydrogel with nanoparticle enhanced detection for small biomolecules

K. S. Booksh, Univ. of Delaware (United States)

We will discuss the development of a novel hydrogel/nanoparticle system for the detection of small biomolecules.

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Defense,
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7674-10, Session 2

FPAA suitability as analog front-end for bio signals

D. P. Morales, Univ. de Granada (Spain)

The use of Field Programmable Analog Arrays (FPAAs) for analog conditioning of electric potentials on the surface of living tissue, such as Electrocardiography (ECG), electromyography (EMG), and electroencephalography (EEG), is presented in this paper. The inherent reconfigurable capability of these devices provides versatility for circuitry dynamic tuning, i.e., changing amplification gains, filters corner frequencies, signal common levels, etc., without interrupting the signal acquisition path. A study of internal circuitry noise sources is presented. Since these analog conditioning circuits are internal to the FPAA chip, it is not possible to measure the noise contributions of each module in the signal path. A method to measure the modules contribution to noise through a digital signal conversion and later processing is presented. For this aim, a sigma-delta modulator is built within the FPAA and exhaustive SNR measurements of this module are performed in order to create an oversampled ADC with 12-bit higher resolution. ADC characterization allows to estimate the contribution of different modules to SNR.

Experimental results are shown using an acquisitions platform that is from by a FPAA from Anadigm and a FPGA from Xilinx that is in charge of FPAA control and digital signal processing.

7674-11, Session 3

Biological imaging using hybrid Raman and fluorescence confocal microscopy

J. Grey, Univ. of New Mexico (United States)

A combined Raman and fluorescence spectroscopic imaging approach is introduced to spatially map chemical structure and variations in nano-enivronments of biological structures. First, we use Raman imaging to interrogate quorum sensing in encapsulated yeast cells in a sol-gel matrix doped with metal nanoparticles. Large enhancements of Raman scatting cross sections are observed due to the surface enhancement effect by exciting the metal plasmon mode (~650 nm). Second, we have developed a multi-color excitation scheme to selectively study Raman and fluorescence response from labeled biological structures, i.e. cells and membranes, that permits detailed correlations between local structure and environments.

7674-12, Session 3

Optical cross talk and surface characterization of SERS nanoimaging bundle substrates

J. B. Kiser, B. M. Cullum, Univ. of Maryland, Baltimore County (United States)

Due to the narrow vibrational bandwidths and unique molecular fingerprints, Raman spectroscopy can be an information rich transduction technique for chemical imaging. Dynamic systems are often difficult to measure using spontaneous Raman due to the relatively weak scattering cross-sections. Using a Raman enhancement mechanism such as SERS, exposure times can be reduced to reasonable levels for dynamic imaging, due to the increased Raman signal intensity.

This paper will discuss the developments of a novel SERS substrate, fabricated on the tips of fiber-optic imaging bundles, which can be integrated into a multispectral imaging system for nanoscale chemical imaging. These substrates are fabricated by tapering imaging bundles to produce 100-nm or smaller diameter core elements. Chemical etching creates uniform cladding spikes onto which a SERS active metal is vacuum deposited, forming the SERS active surface. By varying the amount of silver on the cladding peaks, active surface plasmons can be tuned to various excitation frequencies.

Two factors that influence the quality of the SERS image are the reproducibility of the SERS enhancement across the imaging surface and the optical cross-talk between fiber elements in the imaging bundle. Using SERS images taken of well characterized Raman scatters, the reproducibility across the surface of these probes has been shown to have less than 2% RSD. The cross-talk at the tapered tips is characterized by fluorescent microspheres matched to the element diameter of the SERS bundle. In addition, images of chemically labeled resolution targets will be shown in support of the cross-talk evaluation.

7674-13, Session 3

High-sensitivity hyperspectral imager for biomedical video diagnostic applications

R. Leitner, T. Arnold, M. De Biasio, Carinthian Tech Research AG (Austria)

State of the art hyperspectral imager are generally not applicable to video applications due to (i) the necessary spatial scanning of push-broom approaches or (ii) the impractical switching time of liquid crystal tunable filters. In contrast AOTFs can be built providing switching times far below 1 ms and are thus a suitable technology for an time efficient acquisition of hyperspectral image and video data. We propose an AOTF based hyperspectral imaging approach efficiently synchronised with a high sensitivity EMCCD camera that allows the acquisition of hyperspectral video data. This hyperspectral video data can be used for a live colour display of non-rigidly moving objects and a live diagnostic overlay of a spatially resolved multivariate classification result. Such a system could be used during endoscopic investigations to provide the surgeon parallel to the video data also additional diagnostic information. Two multivariate tissue models of cancer cases of neck-nose-ear excissions (parotis, diaphragma oris, etc.) and thorax surgeries (lung cancer) have been developed. We present the results of these tissue models generated with real data acquired with the prototype for endoscopic cancer detection situations.

7674-14, Session 3

An optical imaging technique for monitoring real-time changes in morphology within the cell, tissue, or whole organism spatial domain

E. S. McLamore, G. Yale, H. Ochoa-Acuña, M. Sepulveda, D. M. Porterfield, Purdue Univ. (United States)

Researchers often utilize tools (e.g., sensors) which monitor biochemical function as an indicator of physiological state, and these tools are often combined with techniques which monitor physical/morphological features (e.g., still imaging) to understand the interplay between form and function (physiology). Studies often depend on human interpretation of microscopy images, where temporally dynamic changes are detected only after significant deviation occurs within small spatial regions over relatively long periods of time. Thus, feasible techniques are required which allow characterization of real time (~msec) changes in cell/tissue/ organism morphology within the visible spectra using highly accessible user-friendly techniques. We introduce a difference imaging technique for monitoring real time changes in morphology within the visible spectra for biological applications. The technique is demonstrated by measuring morphological changes across multiple spatial scales (cell, tissue, and whole organism) in various biological applications (microbial biofilms, Cladoceran (Daphnia magna) embryos, and soybean (Glycine max) roots). When combined with techniques characterizing real time biochemical transport (e.g., respiration, ion/substrate transport), physiology can be directly quantified with a high temporal and spatial resolution.

7674-15, Session 4

Wearable sensors for skin heating and electric field strength in harsh environments

E. J. Klem, J. S. Lewis, A. Dummer, RTI International (United States); K. Taylor, D. E. Thomas, The AEgis Technologies Group, Inc. (United States)

Directed energy test ranges currently lack the capability to measure in-situ either the skin temperature of the subject or the microwave electric field strength at the skin surface. Both parameters would provide important information for system diagnostics, safety, and human response evaluation. We are developing an unobtrusive, wearable sensor system that provides accurate measurements of both skin surface temperature and electric fields at the skin surface.

The system consists of two breakthrough optical sensor technologies that are likely to be useful in other applications. First, an all-optical system has been developed for skin temperature measurements via fluorescence thermometry. This technology provides real-time measurements of the skin surface temperature with virtually no lag time and without perturbing the electric fields. Second, a field strength sensor system is integrated onto the same sensor patches, also addressed via optical fiber. To measure field strength a passive circuit converts the local electric field to a proportional optical signal emanating from a light emitting diode.

We will present preliminary test results that demonstrate precise temperature measurements in the range of 30 - 60ºC using microwave-compatible materials. We will also present results from a preliminary demonstration of microwave detection using a passive optical circuit. These results will demonstrate both the functionality and usefulness of these technologies for directed energy and related applications.

We will also introduce related work on flexible, implantable CMOS device technologies being developed at RTI.

7674-16, Session 4

NIR-based miniature personal hypoxia monitoring system for pilots

R. S. Gurjar, M. Seetamraju, D. Wolf, Radiation Monitoring Devices, Inc. (United States)

Fighter pilots are required to have very high levels of consciousness in order to make quick decisions while subjected to extreme stresses of the aviation environment. Undetected malfunctioning of on-board oxygen supply can lead to hypoxia and loss of consciousness in less than 60 seconds at altitudes over 30,000 ft. The established methods for measuring the oxygen supply to the brain, including the commercially available pulse oximeters, are unreliable for monitoring fighter pilots. We are developing a real-time, versatile near infrared spectroscopic (NIRS) prototype device to detect the onset of hypoxia with high degree of accuracy. The NIRS instrument can simultaneously measure multiple physiological parameters including local hemoglobin concentration ([Hb]), hemoglobin oxygen saturation (SpO2), heart rate (HR) and blood flow rate (FR). The instrument will also have no false positives that can cause unnecessary distraction to the pilot at crucial situations. It uses the principles of dynamic light scattering in combination with wavelength dependent absorption of blood to monitor physiological parameters with high accuracy. For comfort and safety reasons, the instrument will be highly compact, non-invasive and not interfere with any of the numerous life-supporting equipment worn by the pilot. Additionally, the monitor will take into account the statistical variation in an individual's response to altitude and reduced pressure to improve its accuracy and make it more universal.

7674-17, Session 4

In-vitro micro-Raman study of tissue samples for detecting cervical and ovarian cancer with 785-nm laser excitation

S. K. Sharma, L. Kamemoto, A. K. Misra, Univ. of Hawai'i (United States); M. T. Goodman, H. W. Luk, Cancer Research Ctr. of Hawai'i (United States)

We present results of in vitro micro-Raman spectroscopy of normal and cancerous cervical and ovarian tissues excited with 785 nm near-infrared (NIR) laser. Micro-Raman spectra of squamous cells of both cervix and ovarian tissues show significant differences in the spectra of normal and cancerous cells. In particular, several well-defined Raman peaks of collagen in the 775-975 cm-1 region are observed in the spectra of normal cervix squamous cells but are completely absent in the spectra of invasive cervical cancer cells. In the high-frequency 2800-3100 cm-1 region it is shown that the peak area under CH stretching band is much lower than the corresponding area in the spectra of normal cells. In the case of ovarian tissues, the micro-Raman spectra show noticeable spectral differences between normal cells and ovarian serous cancer cells. In particular, the presence of 1158 and 1558 cm-1 peaks of beta-carotene in the spectra of cancerous cells indicates the accumulation of -carotene in ovarian serous cancer cells. These preliminary results show that NIR micro-Raman spectroscopy offers a potential molecular technique for detecting cervical and ovarian cancer from the respective tissues.

7674-18, Session 4

Targeted tuned K-edge computed tomography (CT) imaging of tissue ACE using lisinopril-capped gold nanoparticles

M. F. Daniel, Univ. of Maryland, Baltimore County (United States); O. Aras, T. R. Fleiter, Univ. of Maryland Medical Ctr. (United States)

The development of cardiac and pulmonary fibrosis have been associated with overexpression of angiotensin-converting enzyme (ACE). Moreover, ACE inhibitors, such as lisinopril, have shown a benificial effect for patients diagnosed with heart failure or systemic hypertension. Thus targeted imaging of the ACE is of crucial importance for monitoring of the tissue ACE activity as well as the treatment efficacy in heart failure. In this respect, lisinopril-capped gold nanoparticles were prepared to provide a new type of probe for targeted molecular imaging of ACE by tuned K-edge computed tomography (CT) imaging. These modified gold nanoparticles, with a diameter around 18 nm, showed very high contrast in tuned K-edge CT imaging. These new targeted imaging agents were thus used for in vivo testings on rats.

7674-20, Poster Session

Biometric stress detection using hyperspectral imaging

S. Nagaraj, G. Chan, U.S. Army Armament Research,
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Transient stress results in a variety of physiological transformations as blood flow increases sub-dermally in response to and in proportion with the level of transient stress, thus altering the emissivity and absorption properties of the skin. Physiological indicators such as changes in skin coloration due to sub-dermal vascular adjustments, emergence of abnormal perspiration, and changes in body temperature are parameters which may not be noticeable in the visible range but may be identified more robustly spectrally. Since the skin reflectance shows wavelength dependence in the VIS-NIR region, hyperspectral (HS) images of faces in this spectral range can be correlated to skin color changes and thus can serve as an indicator of physiological/psychological stress. This research has provided a fundamental understanding of biometric intent recognition using hyperspectral imaging of faces in the spectral range from visible to near infrared (VIS-NIR). Signal processing tools and algorithms have been developed using HS face data from human subjects placed in a psycho-physiologically stressful situation to detect stress through changes in dermal reflectance and emissivity. Hyperspectral imaging provides a non-invasive tool to measure stress by selecting and focusing on wavelengths of interest. The additional information available in hyperspectral imaging yields supplementary information that could be exploited for identification of psycho- physiological induced stress. Non-invasive stress detection is a prominent area of research with countless applications for both military and commercial use including border patrol, stand-off interrogation, access control, surveillance and non-invasive, un-attended patient monitoring.

Conference 7675: Photonics in the Transportation Industry: Auto to Aerospace III

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Photonics in the Transportation Industry: Auto to Aerospace III

7675-01, Session 1

Safety railways by using Bragg grating sensors: an industrial case study in Italy

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The ever increasing need for improved safety is among the most important aspects of the railway industry worldwide. A smart condition monitoring system would allow real-time and continuous monitoring of the structural and operational conditions of trains as well as monitoring of the structural health of rail tracks and the location, speed and weight of passing trains of the entire rail systems. Finally, the inclusion of train location, speed restrictions, and train and track conditions to an 'intelligent system' will herald a safer railway industry with reduced maintenance costs, optimized performance and capacity. Railway monitoring requires extensive sensor networks (1,000s of sensors) for measuring strain, vibration, temperature, acceleration, etc. This would be difficult and cost-prohibitive to implement using conventional sensors. Fiber optic sensors, on the other hand, offer many advantages over electrical sensors. These include immunity to EMI, long life-time (>20 years), and massive multiplexing. One of the newest application areas to adopt the use of fibre sensors-and in particular Fibre Bragg gratings (FBGs)-is the railway industry, where it is of greatest importance to know the structural condition of rails, as well as that of cargo and passenger cars to ensure the highest degree of safety and reliable operation.

In this work, we present an industrial case study in Italy carried out by an efficient synergy between industrial realities and research centre. The main objective is the development and validation of a Fiber Bragg grating technology for optic smart system to real-time monitor the structural and operational conditions of rail tracks as well as the location, speed and weight of passing trains of the entire rail systems. In particular, experimental evidence of FBG technology capability to act as efficient diagnostic tool for smart railways is reported.

7675-02, Session 1

Noncontact opto-fluidics-based liquid level sensor for harsh environments

N. A. Riza, S. A. Reza, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

This paper presents a non-intrusive, non-contact liquid level sensor. The proposed sensor is a free-space-based optical sensor that uses opto-fluidic technology-based agile optics to direct light from a laser source to the Liquid Under Test (LUT). The presented design makes the proposed sensor ideal for use in environments where levels have to be determined for caustic or toxic liquids having a small window interface on the containers carrying them. The proposed design uses very low optical power levels (< 100 µW) making it useful for measuring levels of combustible liquids (e.g., jet fuels) which have a danger of being ignited at higher power levels. The proposed sensor can find potential applications in transportation, chemical and aerospace industries.

7675-03, Session 1

Prototype fiber optic imaging sensor for aerospace applications

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Cameras provide excellent in-situ coverage of many events of interest in current state-of-the-art aerospace systems. From departing earth footage to booster separation events, cameras provide the eyes in the skies for real-time situational awareness on the ground. One of the principal challenges with using cameras on high-speed aerospace vehicles is designing the necessary environmental protection systems to isolate the cameras from the harsh aerothermal environment. An established approach makes use of an external fairing or aeropod to provide the requisite isolation. The camera is physically located within the aeropod and the image data is sent electrically from the aeropod to the telemetry system. While this approach has been successfully demonstrated on numerous platforms, there are advantages to moving the camera into the interior of the vehicle and reducing the size of the imaging hardware within the aeropod. If the size of the pod hardware can be reduced, then multiple imaging sensors can be fit within the same aeropod. Alternatively, a smaller sensor can allow for a reduced aeropod size with commensurate reduced drag and aerothermal heating. A prototype fiber optic imaging sensor was developed for aerospace applications by combining a modified medical endoscope with a ruggedized camera. With this new configuration, a significantly smaller aeropod can be used to protect only the distal tip of the endoscope in lieu of the whole camera assembly. The data are acquired through a small lens at the distal tip and transmitted optically through a coherent imaging fiber bundle to a camera that is located within the vehicle. Data from the prototype fiber optic imaging sensor are compared with data acquired with a standard ruggedized camera. Results of these tests are reported in this paper.

7675-04, Session 1

Diagnostic/prognostic health monitoring system and evaluation of Army Composite Bridge

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Composite bridges offer many advantages compared to current steel and aluminum bridges including their lightweight and superior corrosion resistance properties. This paper presents the results of a comprehensive on-going research program to develop innovative Diagnostic Prognostic System (DPS) and a structural evaluation of Composite. Army Bridge (CAB) system. The DPS is founded on three technologies, namely; optical fiber sensing, remote data transmission, and virtual testing. In developing this system, both laboratory and virtual test were used in evaluating different potential damage scenarios. Health monitoring of a composite beam with DPS entailed comparing live strain data to archived strained data in various bridge locations. For temporary field repairs, a family of composite chords was subjected simple ramp loads in search of ultimate strength. As such, composite bridge specimens showcased their strengths, heralded the viability of virtual testing, highlighted the efficacy of field repair, and confirmed the merits of health monitoring.

7675-05, Session 1

Near-infrared spectroscopy for fibre-based gas detection

B. Culshaw, G. Stewart, W. Johnstone, Univ. of Strathclyde (United Kingdom)

This paper presents a perspective on the use of fibre coupled systems to perform remote gas measurements with particular emphasis on the detection of hazardous and/or explosive gases exploiting near infrared tuneable diode laser spectroscopy. The paper concentrates on work with the groups at Strathclyde and OptoSci.

We describe the results for highly multiplexed localised free space absorption cells and for free space systems capable of detecting the presence of gas species over path lengths of 100 metres. We also present preliminary results on remote parametric frequency shifting to address mid infrared absorptions over very long distances using conventional optical fibre links.

The aim of the paper is to highlight the versatility and flexibility of system configurations based upon the tuneable diode laser. These include the use of optical amplifiers, optical sum and difference frequency generation and refined optoelectronic detection system to address specific needs. Additionally we have conducted preliminary evaluations of the prospects for photonic bandgap fibres as guided wave absorption cells complementing our earlier work on evanescently coupled fibre systems.

The basic principles of tuneable diode laser spectroscopy are very well known. We have refined these to derive temperature and/pressure information within the sample environment and additionally to correct for high temperatures and pressures. We have also characterised the response to numerous species, including demonstrating differentiation between species with overlapping spectra, for example water and hydrogen peroxide vapours.

We have accumulated extensive field trial experience. This includes highly multiplexed (over 100 points, one laser source) networks monitoring the performance of landfill sites with special emphasis on the optimisation of power generation therefrom and also on the assessment of spurious seepage of hazardous gases.

The paper will overview the principles and performance of these systems and will include a comparative assessment of the features of the numerous system configuration options.

7675-06, Session 2

Laser beam characterization using agile digital-analog photonics

M. A. Sheikh, N. A. Riza, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Precise knowledge of laser beam parameters is a key requirement in many photonics applications including lasers and optics used in the transportation industry. To the best of the authors knowledge, for the first time, this paper reports on a motion-free laser beam characterization system using electronically agile photonics such as a Digital Micromirror Device (DMD). The proposed system has the capability of measuring all the parameters of a laser beam including minimum waist size, minimum waist location, beam divergence and the beam propagation parameter (M2).

7675-07, Session 2

Fiber optic sensor nanotechnology for detection of hydrogen in space applications

A. A. Kazemi, ARK International (United States); C. Perrotton, Univ. de Strasbourg (France)

Hydrogen detection in space application is very challenging; public acceptance of hydrogen fuel would require the integration of a reliable hydrogen safety sensor. Safety remains a top priority since leakage of hydrogen in air during production, storage, transfer and distribution creates an explosive atmosphere for concentrations between 4% (v/v) - the lower explosive limit (LEL) and 74.5% (v/v) - the upper explosive limit (UEL) at room temperature and pressure. For detecting leakage of cryogenic fluids in spaceport facilities, Launch vehicle industry, aerospace agencies are currently relying heavily on the bulky mass spectrometers, which fill one or more equipment racks, and weigh several hundred kilograms. Optical hydrogen sensors are intrinsically safe since they produce no arc or spark in an explosive environment caused by the leakage of hydrogen. Being a very small molecule, hydrogen is prone to leakage through seals and micro-cracks. This paper describes the ongoing development fiber optic hydrogen sensor system using nano-technology at University of Strasbourg. The system is realized by depositing a specific sensitive modulated layer onto a core of a step index fiber. Contrary to uniform deposit, the structured coating can provide a flexibility to fit with the numerous aerospace constraints. The paper would discuss the sensor design depending on the modulation features used - micrometric or nano-metric. A frequency response of the sensor is expected from the nano structured coating. A continuous response is supposed to be provided by the micrometric modulation. The last design can be obtained with a low cost. A theoretical study was performed and showed good performances in terms of measurement range, sensitivity and response time.

7675-08, Session 2

Hermetic fiber optic modules for avionics applications

A. A. Kazemi, ARK International (United States); E. Y. Chan, The Boeing Co. (United States)

In the past, Boeing had successfully developed and produced the hermetic ARINC 636 fiber optic transmitter and receiver module for the PLANET System in the Boeing 777 commercial airplanes. These hermetic fiber optic modules had demonstrated over 4 millions aggregate flight hours with zero failure; the hermetic fiber seal technology is a key contributor to this outstanding reliability record. Recently, we have investigated failure mechanisms in COTS hermetic mini-dil (dual-in-line) laser modules; and developed new hermetic fiber seal process for low cost mini-dil form factor packaging process. We are also developing cost effective hermetic multi-channel fiber optic array modules technology. The purpose of this paper is to present a novel technique to perform fiber micro-soldering and pigtailing for laser diode mini-packages. This new process will improve the robustness of laser diode fiber pigtailed modules thereby increasing the yield during installation and prevent costly launch failure in future missile launching missions.

7675-09, Session 2

Optical laser cross-link in space-based systems used for satellite communications

A. A. Kazemi, ARK International (United States); A. S. Panahi, Accor USA LLC (United States)

Building high speed communications network using optical links in space has proven to be an extremely complicated task and many such schemes were tried without success in the past. However in the last few years, there has been impressive progress made to bring the concept to fruition in civilian and government-non classified projects. Space-based optical communications using satellites in low earth orbit (LEO) and Geo-synchronous orbits (GEO) hold great promise for the proposed Internet in the Sky network of the future. Laser Communications offer a viable alternative to established RF communications for inter-satellite links and other applications where high performance links are a necessity. This paper will focus on the requirements of the space-based lasers and optics used for beam forming, as well as receiver antenna gain and

detectors used in free space communications. High data rate, small antenna size, narrow beam divergence, and a narrow field of view are characteristics of laser communications that offer a number of potential advantages for system design. Also discussed are the critical parameters in the transmitter, channel, receiver, and link budget that are employed in successful inter-satellite communications system.

7675-10, Session 3

Virtual optical interfaces for the transportation industry

V. Hejmadi, B. C. Kress, USI Photonics Inc. (United States)

We present a novel implementation of virtual optical interfaces for the transportation industry (automotive and avionics). This new implementation includes two functionalities; projection of a virtual interface and sensing of the position of the fingers on top of the virtual interface. The device we are developing include both functionalities in a compact package which has no optical elements to align since all of them are pre-aligned on a single glass wafer through optical lithography. The package contains a CMOS camera which is optimized for the projected interface color and for the IR finger position sensor based on structured illumination. Two versions are proposed: a version which senses the 2d position of the hand and a version which senses the hand position in 3d.

7675-11, Session 3

Compact and fast optical vibration sensor

P. Kiesel, K. Bellmann, N. M. Johnson, Palo Alto Research Center, Inc. (United States)

Compact and sensitive vibration sensors are essential for many strategic market sectors such as structural health monitoring for automobiles, aerospace, transportation, and civil structures. Optical sensors offer many distinct advantages in comparison to their electronic counterparts: high sensitivity, remote and distributed sensing, use in harsh environments, and immune to electromagnetic interference. The functionality of many optical sensors relies on a change in the spectral wavelength response upon an external stimulus (e.g., temperature or strain). A prominent example is the Fiber Bragg Grating (FBG) sensor, in which the reflection spectrum changes in response to the stimulus. A major hurdled to the deployment of FBG sensors is the ability to record the requisite sub-picometer wavelength shifts with a compact, robust, and low-cost interrogation unit. In this presentation we describe a compact and fast-read-out optical vibration sensor that combines a FBG strain sensor with a low-cost, chip-size wavelength detector to resolve sub-pm wavelength shifts. The wavelength-shift detector combines a light sensitive element (e.g., photodiode array or position sensitive device) with a linear variable filter. The laterally varying transmission/reflection properties of the filter induce a spatially dependent signal from the photo-detector that characterizes the wavelength of the incident light. The complete detection system can monitor micro-strain vibrations in the 100 KHz range. High frequency vibrations with sub micro-strain amplitude are even clearly observable in the real-time signal. Therefore this system is well suited to record signature of fast impulse loads on structures that create strain responses with sub micro-strain amplitudes.

7675-12, Session 3

Sunlight to hydrogen

M. Tabib-Azar, The Univ. of Utah (United States)

Great Salt Lakes (GSL) with over 5 Billion gallons of very high salinity water is ideally located in high intensity sunny region (5.5 kWh/m2/Day) within the boundaries of Salt Lake City. GSL's location and water characteristics make it ideal to generate hydrogen using photosynthesis

in a cost-effective and completely environmentally friendly manner. The main objective of this proposal is to develop TiO2-xNx nano-particle based membrane devices that can inconspicuously float near the water surface and using photosynthesis generate hydrogen that will be collected through a network of veins. We are currently developing an efficient technique that uses asymmetric TiO2-xNx nano-particles that preferentially produce photogenerated electrons and holes at two spatially distinct sites to i) prevent rapid electron-hole pair recombination, ii) facilitate H2 and O2 separation to prevent the exothermic recombination, and iii) to absorb sunlight efficiently due to band gap adjustment using quantum size effect and nitrogen incorporation. Our estimated efficiency for hydrogen production is in excess of 10X of the best efficiencies reported so far using similar approach involving TiO2. Our plan in the first year is to incorporate our engineered asymmetric TiO2-xNx in suitable membranes and use microfluidic devices to carefully study efficiency and optimize the hydrogen production efficiency. Scaling studies will be conducted to produce functionalized membranes at large scale for deployment in GSL.

7675-13, Session 3

Fiber optic hydrogen detection system for transportation industry

A. A. Kazemi, ARK International (United States); C. Perrotton, Univ. de Strasbourg (France)

The hydrogen detection is a priority for every transport device or any application where hydrogen is involved.

That is the case for fuel cells and launch vehicle. H2 sensors are necessary to monitor the detection of every possible leak to avoid explosion, which can be highly dangerous according to the hydrogen and other gases concentration.

We present a review of hydrogen sensors used in lab or on site experience. Advantages and drawbacks are put forward. In this context the optical sensor devices are introduced. They show numerous advantages compare to other devices for a lab used or on site. They can be very resistant to shock, vibration and also to thermal influence. They can be increment or give an alert signal for a desired level. Miniaturization and network sensor for data fusion are possible with a low cost. Some technologies are one shot application whereas others are repeatable. In this context we will study the numerous possibilities for guided optic. This study will be based on concepts we have already validated on biochips.

7675-14, Session 3

Interrogation strategies for distributed and multipoint fiber optic sensors

L. U. Kempen, I. F. Saxena, Intelligent Optical Systems, Inc. (United States)

Fiber-optic sensors have matured to allow the detection of chemical and physical parameters at multiple points, or in a distributed fashion along the length of a single optical fiber strand. The electro-optic readout unit connected to the fiber needs to be tailored to the specific sensor application to balance the requirements for spatial and frequency resolution, interrogation intervals, readout time, noise suppression, system size and cost, and other parameters. We will discuss different fiber-optic sensor configurations and suitable readout strategies to meet the requirements of the sensing application.

7675-15, Session 4

Ultra-narrow bandpass filters based on volume Bragg grating technologies

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Free space optical communication between movable platforms, especially communication with non-cooperative targets, requires detecting low intensity signals in conditions of multiple sources of contaminating signals. In this paper, we review recent achievements in ultra-narrow bandpass filters based on volume Bragg gratings (VBGs) recorded in the bulk of photo-thermo-refractive glass. The new types of transmission filters show unique characteristics such as high throughput and bandwidths as narrow as a few picometers at any wavelength from 500 to 2700 nm. The first filter type is formed by the incoherent combination of a Fabry-Perot etalon and a VBG that enables tunable ultra-narrow band transmission with a single resonance. The filters demonstrate a bandwidth down to a few picometers at 1064 nm, a transmission exceeding 90%, an ultra-broad rejection band (several hundreds of nanometers), and an extinction ratio better than 30 dB. The second filter type is based on multiplexed frequency shifted VBGs that form a volumetric Moiré Bragg grating. The filter provides a single resonance with transmission higher than 90% in the middle of the reflection lobe of the VBG, a bandwidth down to a few picometers and high mechanical stability. Both types of ultra-narrow bandpass filters can be used for many applications requiring to transmit a single frequency and to reject other adjacent frequencies, e.g., in Lidars, or for selection of longitudinal modes in laser resonators. The new filters provide a significant advantage in terms of stability, tunability and achievable throughput for a given bandwidth.

7675-16, Session 4

A micro-monolithic optical pressure sensor for high-pressure hydraulic fluid in transportation

M. Guilhem, P. P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France)

The measurement of pressure inside hydraulic embarked system is more an more critical for reasons related to the evolution of control involving a mixing of X by wire (control by electric or optical wire) and activators where a high precision is needed in the pressure sensed data for all the automatic or man assisted by computer controls where an hydraulic device is concerned.

We introduce a micro monolithic hydraulic sensor based on polarization phenomenas that can occur in some polymer material when a sample of this material with an appropriate design has a pressure constraints. We propose a design of a monolithic piece of polymer that by its 3D design will allow to sense the pressure without strong effects related to temperature vibration, etc.

We introduce also the specific photonic signal detection and processing. This process is adapted to mass production at low cost. It could be used with some design modifications as well in automotive than in avionics. We describe the models, the experiments on the specific test bench realized and we discuss the fitting of theoretical and experimental data

7675-17, Session 4

Range-gated active imaging in vehicle with LED illumination

F. Christnacher, M. Laurenzis, J. Poyet, J. Moeglin, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Range-gated active imaging is a prominent technique for night vision, remote sensing and vision through scattering medium or obstacles like fog, smoke and camouflage netting. There are numerous applications as well for military purposes than for civilian uses. Since a few years, ISL works in the field of range gated imaging and realized different prototypes working at various wavelength ranges (solar blind, visible, 800nm, 1.5µm).

As a light source, solid state lasers or laser diodes are mostly used because they are very easy to handle and give a powerful, homogeneous and directive illumination. Recently, light emitting diodes (LED) have made great progress in terms of power, compactness and costs and become more and more good candidate for illumination source. As they can be driven electronically, it is possible to produce very short and high-power light pulses with these components. So range gated imaging can be easily achieved by using them in synchronisation with a sensitive camera.

Further, more and more car manufacturers produce full-LED headlights which gives the possibility to use these headlamps themselves to realize automotive range gated imaging systems. This paper gives an overview of ISL's activities in the domain of LED active imaging, with a special focus on its application to vision improvement in bad weather condition and to security increases in the domain of transport.

7675-18, Session 4

Low-mode, low-loss D-fiber for responsive coating-based sensing in the red

I. F. Saxena, Intelligent Optical Systems, Inc. (United States)

Distributed optical fiber sensors have the capability of operating in sensitive vapor environments such as aircraft fuel tanks, without the need for electrical power at the sensor head, and avoiding concerns of spark-related events. A D-fiber offers such a methodology for gas sensing. In this paper, the separation of the core to flat surface and the core radius and their effect on losses are determined.

The loss and the sensitivity are optimized and a design that shows high sensitivity in the 650nm wavelength is reported.

7675-19, Session 5

Broadband fiber optic 1x2 switch using an electrically controlled liquid lens

N. A. Riza, P. J. Marraccini, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

To the best of our knowledge, proposed is the first liquid lens technology-based 1x2 fiber optic switch using a single Electronically Controlled Variable Focus Lens (ECVFL). By controlling the focal length of the liquid ECVFL, the input optical beam is spatially adjusted to couple into the respective output fiber port. The switch demonstrates a 3-dB bandwidth of 175 nm, with a center frequency of 1550 nm, and features low power consumption suitable for mobile applications. The proposed switch can be useful in communication and control systems, in roadway sensor systems, vehicle detection systems, and monitoring systems.

7675-20, Session 5

High-security digital optical tags for automotive/avionics parts anticounterfeiting

E. Boisdur, Horus Technologies (France)

Horus technologies develops novel optical tags based on planar digital micro-optics. These tags are calculated by computer, fabricated as masters via optical microlithography and replicated in mass by plastic embossing. Such tags are composed of several different levels of anticounterfeating features, ranging from traditional holographic patterns, to OVIDs, to micro-holograms, to machine readable digital holograms storing holographic 1D and 2D bar codes. These tags have a double aim: anticounterfeating of automotive/avionic parts and providing the engineer using an appropriate tag reader with all the technical information referring to these parts.

7675-21, Session 5

Specific signal processing for vibrations and sounds detected by intrinsic optical fiber sensor

M. Arezki, P. P. Meyrueis, N. Javahiraly, Ecole Nationale Supérieure de Physique de Strasbourg (France)

We introduce an optical fiber intrinsic vibration sensor, that can operate as a high performance microphone, associated to a specific signal processing method allowing to use this device without the noise disturbance coming from its high sensitivity to many phenomenas. We describe intrinsic optical fiber sensor operating with the design that we propose.

The problem is to eliminate all the noise and to select the relevant signal. Since the sensor has a very high dynamic and that it can sense sound with a very large aperture. The design allows the detecting of a range of vibrations wished without many other vibrations that are unwanted.

We first describe the design of the sensor, we justify our selection of the telecom optical fiber that we used and the polarization modulation effect that we have implemented. We show that this device can be miniaturized by using integrated optics technology.

We propose a new signal processing method based on double sensing that allow to have a clean signal even in very poor conditions. We demonstrate some cases of optimal sound sensing.

We compare the fundamental and experimental results and we discuss the output of this comparison.

We conclude by a prospective description of what could be a commercial continuation of our prototyping work.

7675-22, Session 5

New PV conversion phenomena which can be activated on very high efficiency silicon devices for small foot prints cells (automotive)

Z. T. Kuznicki, P. P. Meyrueis, Ecole Nationale Supérieure de Physique de Strasbourg (France)

The nowadays quite indispensable enhancement of PV conversion efficiency cannot be obtained without new mechanisms. The most useful of these mechanisms have to appear in the front face of the device, i.e. in the emitter, so as to allow exploitation of the energetic photons of the solar spectrum. Such an improvement can be realized through a multistage PV conversion starting by primary generation (photon absorption) followed by secondary generations (hot carrier collisions with low-energy generation centers). This cascade-like process is possible,

for example, in multiinterface devices containing several emitter strata. Some of these strata assume the primary free-carrier generation while others do the secondary free-carrier generation. The new mechanisms can be used for the adjustment of the Si quantum converter to the whole solar spectrum thanks to the multistage conversion.

In this work we report investigations of new mechanisms appearing in test Si devices with nanoscale Si-layered systems, nanostructured Si (up to a PV metamaterial) with different multiinterface architectures, electronic passivations, front grids, collecting electrodes and so on. These transformations allow a free-carrier multiplication which leads to, in suitable conditions, internal quantum efficiencies exceeding unity. The best test collection efficiency we have measured up to now results in 1.35 electrons per incident photon. At least one of the two main limitations of conventional Si-based (bulk or thin film) solar cell performance, i.e. the only one electron-hole pair generation by energetic photons can be then overcome. The thermodynamic limit of conventional photovoltaic conversion is limited at 30%, while in the case of the mechanism reported here, if can be propelled above 60%.

7675-23, Session 5

Diaphragm resonance-based fiber optic hydrophone

I. F. Saxena, Intelligent Optical Systems, Inc. (United States)

Passive hydrophones that can be used for a variety of underwater monitoring with a minimal footprint are investigated. Fiber-optic hydrophones have been used for offshore moored applications and offer large area coverage. A resonant hydrophone using an FBG transducer for bandwith limited operation is described. When powered by a battery this system is suitable for off-mooring applications such as in autonomous underwater vehicles.

7675-24, Poster Session

Research on the methods to minimize the startup null drift of four frequency ring laser gyro

J. Yang, National Univ. of Defense Technology (China)

For the application of RLG in fast startup situation such as missiles, the startup null drift should be minimized. This paper studies the physics mechanism of startup null drift of four frequency RLG. Based on the analysis of the physics process of the gyro warming up, five main affecting factors are pointed out: (1) negative effect of the quartz crystal; (2)variation of the frequency stabilizing position; (3)variation of the sensitivity to magnetic field; (4)variation of the light path;(5)variation of the light intensity. Then every factor's contribution to the startup null drift is experimentally evaluated, that is 33%, 21%, 18%,10%,7% respectively. At the same time, the corresponding solutions are put forward: (1) 8-like non-planar cavity technology for eliminating the effect of quartz crystal; (2)dispersion equalization technology for decreasing the sensitivity of gyro drift to frequency stabilizing position; (3)suitable choice of the frequency stabilizing point for decreasing the sensitivity to magnetic field; (4)novel cavity length and angle controlling mirror for stabilizing the light path. (5)auto-gain control technology for stabilizing the light intensity. The experiment shows that, the solutions can decrease the startup null drift from 5Hz to 0.05Hz and the warming-up time from 3 hours to 15 minutes, which are effective to improve the temperature performance of laser gyro.

Conference 7676: Sensing for Agriculture and Food Quality and Safety II

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7676-01, Session 1

Influence of temperature on visible and near-infrared spectra and the predictive ability of multivariate models

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When vibrational spectra are measured on- or in-line for process analytical or control purposes, the spectra may undergo fluctuations in response due to fluctuations in temperature or humidity that must be taken into consideration when developing calibration models. In this paper, the influence of temperature fluctuations on visible and near-infrared (Vis/NIR) spectra and their effect on the predictive power of calibration models such as PLS and LS-SVM have been studied. The sample was juicy peach. Soluble solids content in juicy peach was detected. The resulting prediction errors of a test set are compared. The results shows influence of temperature on Vis/NIR spectra of the juicy peach exists. For data with no temperature variation, the models perform best with low error. The implicit inclusion of the different temperatures in the calibration models results in a low prediction accuracy.

7676-02, Session 1

Near-infrared hyperspectral imaging for quality analysis of agricultural and food products

C. B. Singh, D. S. Jayas, J. Paliwal, Univ. of Manitoba (Canada); N. D. G. White, Agriculture and Agri-Food Canada (Canada)

Agricultural and food processing industries are always looking to implement real-time quality monitoring techniques as a part of good manufacturing practices (GMP) to ensure high-quality and safety of their products. Near-infrared (NIR) hyperspectral imaging is gaining popularity as a powerful non-destructive tool for quality analysis of several agricultural and food commodities. This technique has the ability to analyse spectral data in spatially resolved manner (i.e., each pixel in the image has its own spectrum) by applying both conventional image processing and chemometric tools used in spectral analyses. Hyperspectral imaging technique has demonstrated potential in detecting defects and contaminations in meats, fruits, cereals, and processed food products. This paper discusses the methodology of hyperspectral imaging in terms of hardware, software, calibration, data acquisition and compression, and development of prediction and classification algorithms. This paper presents a thorough review of the current applications of hyperspectral imaging in the analyses of agricultural and food products.

7676-03, Session 1

Measuring the capsaicinoids contents in red pepper powder by using the near-infrared spectroscopic method

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Consumers have complained the non-uniform spicy of Kimchi and Korean red-pepper paste, even though the capsaicinoids contents and taste for the same variety of red pepper can be various by the different sunshine rate, precipitation amount and distinctive soil features. To resolve the non-uniformity, many researchers have been tried to find the rapid measuring methods for the capsaicinoids, the main component of spicy, but methods, such as using the HPLC, are time-consuming and costs are high for the multiple samples. Thus, food company sampled and measured the amount of capsaicinoids and showed the level of spicy.

In this research, the near-infrared absorption from 1100 ~ 2300 nm was used to measure capsaicinoids content in red-pepper by using the Acousto-optic tunable filters (AOTF) spectrometer with sample rotating plate and power supply unit.

Non-spicy red-pepper samples from one location (Younghwang-gun. Korea) were mixed with spicy one (var. Chungyang) to make 264 samples. The Partial Least Square Regression Model (PLSR model) to predict the capsaicinoids content was developed with measured spectra by AOTF spectrometer and analyzed the amount of capsaicinoids by HPLC. The Standard Error of Prediction (SEP) for unknown sample with cross validation was ±9.3mg%. Forty three different variety samples from 14 different locations with three different granularities were used to measure the 3741 spectra, and the SEP result from the cross validation showed ±14.6mg%. This value was slightly higher than the same location, but results showed that this method can be used to grading the spicy for the red-pepper.

7676-04, Session 1

Food quality assessment by NIR hyperspectral imaging

M. B. Whitworth, S. J. Millar, Campden BRI (United Kingdom)

Near infrared reflectance (NIR) spectroscopy is well established in the food industry for rapid compositional analysis of bulk samples. NIR hyperspectral imaging provides new opportunities to measure the spatial distribution of components such as moisture and fat, and to identify and measure specific regions of composite samples.

An NIR hyperspectral imaging system has been constructed for food research applications, incorporating a SWIR camera with a cooled 14 bit HgCdTe detector and N25E spectrograph (Specim Ltd, Finland). Samples are scanned in a pushbroom mode using a motorised stage. The system has a spectral resolution of 256 pixels covering a range of 970-2500nm and a spatial resolution of 320 pixels covering a swathe adjustable from 8 to 300mm. Images are acquired at a rate of up to 100 lines/s, enabling samples to be scanned within a few seconds. Data are captured using SpectralCube software (Specim) and analysed using ENVI and IDL (ITT Visual Information Solutions).

Several food applications are presented. The strength of individual absorbance bands enables the distribution of particular components to be assessed. Examples are shown for detection of added gluten in wheat flour and to study the effect of processing conditions on fat distribution in chips. More detailed quantitative calibrations have been developed to study evolution of the moisture distribution in baguettes during storage at different humidities, to assess freshness of fish using measurements of whole cod and fillets, and for prediction of beef quality by identification and separate measurement of lean and fat regions.

7676-05, Session 1

UV/visible/near-infrared reflectance spectroscopic determination of cotton fiber and trash content in lint cotton waste

Y. Liu, G. R. Gamble, D. P. Thibodeaux, USDA Agricultural Research Service (United States)

Lint cleaning at cotton processing facilities is performed in order to reduce the non-lint materials to minimal levels with minimal fiber damage. The resultant waste contains some degree of cotton fiber having equal quality to the fiber in the bale, and hence is of great concern for operating cost and profit. Traditional methods for measuring the non-lint material or trash in cotton, including Shirley Analyzer and HVI, are labor intensive and time consuming. UV / visible / NIR spectroscopy, a rapid and easy sampling technique, was examined for its feasibility in determining the relative proportions of cotton fiber and trash in lint cotton waste. Cotton waste was scanned in the region of 220-2500 nm and the reference value was measured by Shirley Analyzer. Partial least squares (PLS) regression models were developed in various spectral ranges and then compared. Though there are obvious spectral differences in the visible and NIR regions between trash and cotton fiber, the model performance from a narrow NIR region of 900-1700 nm was nearly equivalent to that from the full 226-2494 nm spectral region. Meanwhile, simple 2-band difference algorithms utilizing 2 unique bands were developed and also suggested the effectiveness of the NIR bands at 900 and 1135 nm in the assessment of fiber and trash fractions in cotton waste. The overall result indicated that NIR prediction of visible trash and cotton fiber in cotton waste is limited to screening purpose for probable reasons of heterogeneous trash distribution, relatively small sampling area, and gravimetric reference method.

7676-06, Session 1

Damage and quality assessment in wheat kernels by NIR hyperspectral imaging

S. R. Delwiche, M. S. Kim, USDA Agricultural Research Service (United States)

Individual kernels of wheat with known causes of damage are to be scanned with a newly developed hyperspectral imaging system that operates in the 1,000 to 1,700 nm region. Damage conditions, as identified by official (USDA) inspection, include black tip, frost, heat, and mold. Images are collected by this push broom system at a spatial pixel resolution of less than 0.1 mm x 0.1 mm and binned into approximately 75 wavelength bands. Analysis for detection of the damage conditions includes band ratioing, principal component analysis, and morphological feature extraction. Additionally, regional features attributed to kernel physiology (e.g., endosperm, germ, crease) and localized damage are reported. Recommendations of wavelengths for use in multispectral design are provided.

7676-07, Session 2

Detection of organic residues on food processing equipment surfaces by spectral imaging method

J. Qin, W. Jun, M. S. Kim, K. Chao, USDA Agricultural Research Service (United States)

Organic residues on equipment surfaces in food processing plant could generate cross contamination and thus increase the risk of unsafe food for consumers. Current pre-operational sanitation monitoring mainly relies on human visual inspection, which is subjective, labor-intensive, and time-consuming. The objective of this research was to investigate the potential of spectral imaging technique for rapid inspection of organic residues on poultry processing equipment surfaces. Chicken fat, blood, and feces are major residues that are attached to the equipment surfaces, and stainless steel is the commonly used material in making poultry processing equipments. Hence they were chosen to be tested in this study. A portable spectroscopic system equipped with a fiber optic reflection probe was used to collect reflectance spectra from organic samples and stainless steel plates in both visible (400-900 nm) and near-infrared (900-1700 nm) regions. Fluorescence spectra were obtained using a UV LED excitation source with a spectral output at 380 nm. Hyperspectral images were also acquired for the samples tested

in this study. Spectral characteristics of reflectance and fluorescence for organic residues and stainless steel were determined. Chemometric analysis was applied to differentiate organic residues from stainless steel. The capabilities of reflectance and fluorescence for inspecting poultry processing equipment surfaces were evaluated and compared. Important wavelengths that have the potential to be used in practice (e.g., a handheld device for equipment inspection in poultry processing plant) were identified, and spectral processing and classification algorithms were developed.

7676-08, Session 2

Microwave-assisted laser-induced breakdown spectroscopy for trace detection in soil and food

Y. Liu, M. Baudelet, M. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Laser-induced plasma spectroscopy has become a standard technique for analytical studies. Its use is mainly due to its unique benefits: all-optical technique, quasi-no preparation of the sample, multi-elemental signatures. The last feature is the main interesting one when you consider its application for complex samples as organic and biological samples. To enhance their emission and as a consequence of better signal-to-background and signal-to-noise ratios, extending their excitation in a time-extended plasma has been proposed. The absorption of microwave radiation of several milliseconds by the plasma is known to extent its lifetime and increase its emission at the same time.

The plasma is created by a nanosecond Nd:YAG laser pulse and coupled in a 2.45 GHz resonant microwave cavity. The MW pulse duration can be set up to 20 ms, allowing the plasma lifetime to be extended by a factor of the order of 10,000. We present analytical properties of microwave assisted LIPS for detection of low to trace concentration elements in ceramics and biological samples. Our results show enhancement of signal from elements present (Titanium or Potassium for example) by factors of several thousands. Critic on the analytical usefulness of this enhancement is made by measuring to what extend the microwave enhanced plasma maintains the sample stoichiometry and if the conditions of Local Thermodynamic Equilibrium are improved in order to easily invert the LIPS signal to elements concentrations via standard-less algorithmic methods.

7676-09, Session 2

Microwave technology and system for milk quality inspection and pasteurization

Y. V. Savenko, F. Repa, National Technical Univ. of Ukraine (Ukraine)

The paper reports result of research work on development of microwave technology and system for milk quality inspection and pasteurization. It has been developed microwave technique for material composition and quality analyses. It has been developed and investigated microwave technology for milk quality inspection based on developed microwave technique. For investigation of microwave technology for milk quality inspection it has been developed microwave system. In particular, milk quality inspection was investigated by measuring of fatness based on measuring of measuring cell propagation ratio. In addition it has been developed microwave technology and system for milk pasteurization with milk quality inspection.

7676-10, Session 2

Effects of muscle structures on two-dimensional reflectance in beef

G. Yao, Univ. of Missouri-Columbia (United States)

Our recent studies found that the optical reflectance in skeletal muscle had a unique geometric pattern. This pattern can be characterized using a set of five parameters extracted from each image. A multi-spectral imaging system was developed to acquire reflectance images in beef samples varying in sarcomere length, collagen content and proteolysis. The acquired images were analyzed using the aforementioned method to extract the following five parameters. Two parameters, q and B, were calculated by fitting the equi-intensity contours of the reflectance pattern with a parametric equation. Two spatial gradients parallel and perpendicular to muscle fibers were calculated using numerical fitting. The total scattering intensity was calculated by removing the specular reflectance at the center of incidence. Using this method, we studied the effects of sarcomere length, college content, and proteolysis on the two-dimensional reflectance in beef muscles. The possibility of applying this technology for beef quality assessment was also discussed.

7676-11, Poster Session

Bruise detection on Chinese pears by nuclear magnetic resonance imaging technology

S. Zhou, Y. Ying, Zhejiang Univ. (China)

A new method was developed to inspect the subtle bruises on fruits with nuclear magnetic resonance imaging technology. Hebei ya Pears Were adopted as the experimental object. The pears' Nuclear Magnetic Resonance T2-weighted images were got by horizontal scanning.Image pre-processing was finished by MATLAB software. After that the object space was segmented by auto thresh method and the boundary was also extracted by CANNY operator. At last the corner detection method was used to detecting whether the pear had subtle bruises. The experimental results showed that subtle bruises inspection on fruits with NMR technology was realized. The accuracy is 92.1% and 100% respectively for subtle bruises and good pears.

7676-28, Poster Session

Spatial variation of water and soil erosion in Donghe basin based on SWAT model

A. Liu, J. Chen, J. Wang, Z. Liu, X. Huang, China Land Surveying and Planning Institute (China); C. Yan, Jiangsu Land Surveying and Planning Institute (China)

The Donghe basin is one of the typical regions with serious water and soil erosion in Kaixian county of Chongqing city. In this study the spatial distribution variation of water and soil erosion in Donghe basin is analyzed based on a comprehensive method that integrates SWAT model with a Geographic Information System and remote sensing technology. SWAT is a physical based model that requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring within the watershed. Firstly, with the Donghe basin as a study area, using the spatially distributed and mechanism-based SWAT model, the distributed hydrological and sediment model are developed to simulate the runoff and sediment production of Donghe basin. Then the model is calibrated and validated against observed runoff and sediment data from 2003 to 2004, the validated result shows a deterministic coefficient of 0.93. Finally the spatial distribution of the water and soil erosion of Donghe is analyzed. The results show that the mean sediment production of Donghe basin is 30.7 t/ha a, the maximum sediment production of its sub-watersheds is 212.7 t/ha a, and the minimum is 0.3 t/ha a. There is an obviously clustering feature of sub-watersheds distribution with different sediment production level. The area

of the high erosion, strong erosion and violent erosion account for 30% of the whole basin area, the other soil erosion area occupy 70%.

7676-29, Poster Session

Technical system of land survey and monitoring and its future schemes in China

J. Wang, China Land Surveying and Planning Institute (China)

Land is as a terrestrial bio-productive system. China's land resources are extremely scarce. There is a pressing need for building the technical system of land survey and monitoring for detail knowledge about the current situation of land use, land value and land property right of each piece of land in the whole country for land use and management. Many works of land survey and monitoring in China have been finished providing references directly for the macro decision-making and making the national economic and social development planning. However, there were limited in integrity, systemization, and standardization and some of works about survey and monitoring were carried out in the early period and results were not updated in time. The purpose of the paper is to establish the framework of systemized technical system of land survey and monitoring for guidance of future national work of land survey and monitoring. The study was through comparing and analyzing the finished and ongoing works of land survey and monitoring. Results indicated that the technical system is constituted by 7 sub-systems. It will integrate land survey and monitoring, land evaluation, and information sharing service into a whole. The regional arrangement of land survey and monitoring was proposed in the study. Seven regions of implementation of land survey and monitoring were divided, including the northeastern region, eastern coastal region, central region, southwestern region, northwestern region, Xinjiang Urgur region, and Qinghai-Tibetan region. Their objectives and contents in each region are different by their regional characteristics. It is for guidance of future work arrangements about national land survey and monitoring in China based on national land resources background and economic development demands.

7676-30, Poster Session

The development of the methodology of geographic image cognition on land degradation

J. Wang, China Land Surveying and Planning Institute (China)

For the extraction of land degradation information we should use not only information on climate, soil, vegetation, physiognomy, land use and its productivities, but also the knowledge and methodologies of geosciences. It is of importance to study some conceptual issues about geographic image cognition (GEOIC) on land degradation. The study is to discuss some conceptual issues and the theoretical background of the methodology of geographic image cognition (GEOIC) on land degradation for building its methodological framework. And some issues concerning the methodology of GEOIC on land degradation, especially the factors of impacting human's visual cognition, were discussed. The results indicated that the GEOIC is the objectification cognition on remote sensing images and multi-source information using geo-knowledge. As an integrated approach, it is the extension of the methodology of OBIA. The key objective of the GEOIC on land degradation is to simulate the function and process of the visual interpretation by experts, and extract spatial features, spatial object and spatial pattern of land degradation under the cognition mode of feature-object-pattern from remote sensing images and multi-source information. The methodology of the GEOIC is realized through the segmentation of geo-objects or meaningful image objects using remote sensing information, geographic information, vegetation, soil, and other ancillary information with geosciences knowledge and intelligence.

7676-32, Poster Session

Real-time near-infrared spectroscopic inspection system for adulterated sesame oil

S. Kang, K. Lee, J. Son, Rural Development Administration (Korea, Republic of)

Because the sesame oil is very popular and expensive in Korea, it has been often mixed with other vegetable oils for profiteering. The determination method of adulteration of sesame oil should use the dangerous chemicals and it takes long time to analyze by experts. The objective of this research is to develop an economical and manageable adulteration determination system for sesame oil. The developed system has light source, measuring unit, spectrophotometer, fiber optics and data acquisition system. The near-infrared transmittance spectroscopic method was used to develop the prediction model with Partial Least Square (PLS). Using glass tube with 8mm diameter, the correlation coefficient values were 0.98 for corn oil, perilla oil, and soybean oil. The Standard Error of Correlation for corn oil, perilla oil, and soybean oil were 6.32%, 6.16%, and 5.67%, respectively. From the prediction model, the correlation coefficients of corn oil, perilla oil, and soybean oil were 0.98, 0.97 and 0.98, respectively. The Standard Error of Prediction (SEP) for corn oil, perilla oil, and soybean oil were 6.52%, 6.89% and 5.88%, respectively. The results indicate that the developed system can potentially be used as a non-destructive adulteration analysis method for the rapid and simple non-chemical measurement of sesame oil mixed with other vegetable oils.

7676-33, Poster Session

On-line determination of pork color and intramuscular fat by computer vision

Y. Liao, X. Wu, Y. Fan, F. Cheng, Zhejiang Univ. (China)

The objective of this study was to evaluate the potential of the use of computer vision to determine CIE L*a*b* and content of intramuscular fat (IMF) on-line. Images of the pork chop samples in 211 pig carcasses were captured at the speed of 0.25 m.s-1. Color values of CIE L*a*b* and IMF content were measured using colorimeter and chemically extractable as reference.Composite image after arithmetic subtraction operation was binarized with simple thresholding to remove the background and then used KSW algorithm in conjunction with selecting regions to eliminate the surrounding fat of longissimus dorsi muscular (MLD) and the image contains MLD only. Red, green and blue (RGB) values were obtained from images and five methods were used for transforming RGB values to CIE L*a*b* values. Region growing with multiple seed points was applied to mask out the IMF pixels within the intensity corrected images. The performance of the proposed algorithm was verified by compared between the quality characteristics obtained by image processing and reference values. Supposed the fact that considerable variation of color and complex on the pork surface, CIE L*, a* and b* color of MLD could be predicted with correlation coefficient of 0.84, 0.54 and 0.47 respectively; and IMF content could be determined with correlation coefficient more than 0.70. Results demonstrate that computer vision was possible to evaluation CIE L*a*b* and IMF content on-line but need further research.

7676-34, Poster Session

Quantitative analysis and detection of adulteration in pork meat using near-infrared spectroscopy

Y. Fan, F. Cheng, Zhejiang Univ. (China)

Authenticity is an important food quality criterion. Rapid methods for confirming authenticity or detecting adulteration are increasingly demanded by food processors and consumers. Near infrared (NIR) spectroscopy has been used to detect economic adulteration in pork meat. Pork meat samples were adulterated with liver and chicken in 10% increments. Prediction and quantitative analysis were done using raw data and pretreatment spectra. The optimal prediction result was achieved by partial least squares(PLS) regression with standard normal variate(SNV) pretreatment for pork meat adulterated with liver samples, and the correlation coefficient(R value), the root mean square error of calibration(RMSEC) and the root mean square error of prediction (RMSEP) were 0.97706, 0.0673 and 0.0732, respectively. The best model for pork meat adulterated with chicken samples was obtained by PLS with the raw spectra, and the R value, RMSEP and RMSEC were 0.98614, 0.0525, and 0.122, respectively. The result shows that NIR technology can be successfully used to detect adulteration in pork meat adulterated with liver and chicken.

7676-35, Poster Session

Detection of pesticide residues in agricultural product based on diffuse reflectance Raman spectroscopy

K. Kim, Y. Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

In this paper, a nondestructive pesticide residue measurement of the agricultural products based on the diffuse reflectance Raman spectroscopy (DRRS) is described. The Raman spectroscopic system consists of diode laser generating continuous wave with wavelength of 785 nm, multimode optical fibers, focusing probe with two prism to detect the Stokes radiation, multi-channel detectors with charge couple device, sample holder, personal computer and so on. DRRS spectra of 10 kinds of pesticides for paprika sample were measured and analyzed. The differences in intensities and absorptions Raman shift at Raman spectra among pesticides were found. The principal component analysis was applied to recognize the kinds of pesticides. By using DDRS, it is possible to detect the multi-elements of pesticide residues in a paprika sample. As a conclusion, a rapid inspection of food safety will be possible based on diffuse reflectance Raman spectroscopy.

7676-12, Session 3

Non-destructive quality measurement of cherry tomato using hyperspectral imaging technique

B. Cho, Chungnam National Univ. (Korea, Republic of); M. S. Kim, USDA Agricultural Research Service (United States); D. Kim, Chungnam National Univ. (Korea, Republic of); Y. Kim, SangMyung Univ. (Korea, Republic of); K. Chao, USDA Agricultural Research Service (United States)

Cherry tomato is one of major export vegetables in South Korea. Color, size, defects, firmness, and sugar/acid content are considered to be important quality attributes of consumer acceptability. Accurate quality sorting of the products is necessary to satisfy the consumer's demand as well as to preserve the quality during transportation and distribution. Current quality measurement of cherry tomato is dependent on drum type shape sorting machines for only size sorting. Development of sensitive quality measurement methods is necessary to ensure accurate quality sorting of cherry tomato. In this study, uses of a high spatial resolution hyperspectral reflectance are presented as tools for non-destructive measurement for cherry tomato quality, such as defects, bruising damage, and sugar/acid content. Several multivariate analyses as well as simple ANOVA classification methods were explored to select optimal combination of visible/NIR wavebands. Results demonstrated good potential of the hyperspectral reflectance imaging for quality measurement of cherry tomatoes. Quality prediction models with several optimal spectral wavebands determined in this study could be used for developing a real-time quality sorting machine for cherry tomato industry.

7676-13, Session 3

Single aflatoxin contaminated corn kernel analysis with fluorescence hyperspectral image

H. Yao, Z. Hurska, R. Kincaid, A. E. Ononye, Mississippi State Univ. (United States); R. L. Brown, T. E. Cleveland, USDA Agricultural Research Service (United States)

Aflatoxins are toxic secondary metabolites of the fungi Aspergillus flavus (A. flavus) and A. parasiticus, among others. Aflatoxin contaminated corn is toxic to domestic animals when ingested in feed and is a known carcinogen associated with liver and lung cancer in humans. Consequently, aflatoxin levels in food and feed are regulated by the Food and Drug Administration (FDA) in the US, allowing 20 ppb (parts per billion) limits in food and 100 ppb in feed for interstate commerce. Currently, aflatoxin detection and quantification methods are based on analytical tests. These include either chromatography methods such as thin-layer chromatography (TCL) and high performance liquid chromatography (HPLC) or immunochemical methods such as radioimmunoassay (RIA), enzyme-linked immunosorbent assay (ELISA), and immunoaffinity column assay (ICA). These analytical tests require the destruction of samples, and are costly and time consuming. Thus, the ability to detect aflatoxin in a rapid, non-invasive way is crucial to the grain industry, particularly to corn industry. Hyperspectral imaging technology offers a non-invasive approach toward screening for food safety inspection and quality control based on its spectral signature. The focus of this paper is to analyze fluorescence emission spectra of aflatoxin contaminated single corn kernels using fluorescence hyperspectral imagery. Field inoculated corn kernels will be used in the study. Contaminated and control kernels under long wavelength UV excitation will be imaged using a visible near-infrared (VNIR) hyperspectral camera. The imaged kernels will be chemically analyzed to provide reference information for image analysis.

7676-14, Session 3

Calibration of a novel fluorescence hyperspectral imaging system for agricultural inspection and detection

A. E. Ononye, H. Yao, Z. Hruska, R. Kincaid, Mississippi State Univ. (United States)

Fluorescence hyperspectral imaging is increasingly being used for food quality inspection and detection of potential food safety concerns. Mississippi State University is using a novel self scanning pushbroom hyperspectral imager for this type of work due to its flexibility and ability to be used in a variety of applications. To increase the use of this technique there however has been a tendency to use low cost off-the-shelf hyperspectral sensors which are typically not radiometrically calibrated. To ensure that these systems are optimized for response and analysis repeatable, it is imperative that the systems be both radiometric and spectrally calibrated specifically for fluorescence imaging. Fluorescence imaging provides several challenges such as low signal, stray light and a large signal dynamic range that are improved with careful radiometric calibration.

We present a technique for radiometrically and spectrally calibrating this novel and other types hyperspectral imagers that includes flat fielding and the conversion of digital numbers to radiance being used for fluorescence imaging. Results show that this method can be adopted for calibrating fluorescence and reflective hyperspectral imaging systems in the visible and near infra-red domains.

7676-15, Session 3

Classification of fecal contamination on leafy greens by hyperspectral imaging

W. Jun, M. S. Kim, USDA Agricultural Research Service (United States); S. Kang, Rural Development Administration (Korea, Republic of); K. Chao, D. E. Chan, USDA Agricultural Research Service (United States)

Foodborne illnesses caused by pathogenic bacteria are increasingly being linked to fresh produce. Since animal manure is thought to be a potential pathogen reservoir, animal manure could introduce fecal pathogens to fresh produce. This has raised concerns regarding public health and environment. Recently, we have worked on developing the detection methods for fecal matter on leafy greens. Leafy greens have been contaminated with feces and hyperspectral images of leaves were acquired to investigate the potential for the detection of fecal contaminants. The results of this study showed great potential for classifying animal feces on leafy greens by hyperspectral imaging. The details of results will be discussed in presentation at the meeting.

7676-17, Session 4

Characterization of the optical properties of normal and defective pickling cucumbers and whole pickles

R. Lu, USDA Agricultural Research Service (United States); D. P. Ariana, H. Cen, Michigan State Univ. (United States)

Pickling cucumbers are susceptible to mechanical damage during harvest, transport and postharvest handling. Mechanical injury typically causes soft, watery tissue, split carpel, or hollow center in pickling cucumbers, which will lead to bloating problems during brining, thus lowering the quality of final pickled products. In order to develop an optical system for effective inspection of defective pickling cucumbers/pickles, it is important to understand their optical absorption and scattering properties as related to mechanical injury. This research was conducted to measure the absorption and scattering properties of normal and mechanically injured pickling cucumbers and whole pickles. A hyperspectral imaging-based spatially-resolved technique was used in the research. Fifty freshly harvested 'Journey' pickling cucumbers were used in the experiment. Spatially-resolved hyperspectral images were first acquired from the normal pickling cucumbers. Thereafter, the cucumbers were subjected to rolling under mechanical load to induce internal damage. The damaged cucumbers were imaged again. In addition, the optical properties of 20 good whole pickles and 20 bloated whole pickles were also determined by following the same procedure as that for the fresh pickling cucumbers. An inverse algorithm for the diffusion model was used to extract the absorption and reduced scattering coefficients of the pickling cucumber and pickle samples for the spectral range of 500-1,000 nm. This paper presents the measured optical properties of the two classes of pickling cucumbers and pickles, and their implications for optical inspection of the quality of cucumbers and pickles are discussed.

7676-18, Session 4

Hyperspectral imaging methods for high-throughput online food safety and quality inspection

M. S. Kim, K. Chao, USDA Agricultural Research Service (United States)

New hyperspectral line-scan imaging technologies can deliver high-speed online safety and quality inspection of food and agricultural products on high-throughput processing lines. ARS scientists have

developed line-scan hyperspectral imaging methods for high-speed inspection on commercial processing lines, capable of simultaneous multiple inspection algorithms for different safety and quality problems. Adaptable to a broad range of problems and commodities, the line-scan hyperspectral imaging platform will be critically useful for both research and commercial food safety and quality inspection applications. We present recent development and application of the rapid line-scan image-based online inspection for apples and chicken carcasses.

7676-19, Session 4

Line-scan hyperspectral imaging for real-time poultry fecal detection

B. Park, S. Yoon, W. R. Windham, K. C. Lawrence, M. S. Kim, K. Chao, USDA Agricultural Research Service (United States)

The ARS multispectral imaging system with three-band common aperture camera was able to inspect fecal contaminants in real-time mode during poultry processing. Recent study has demonstrated several image processing methods including binning, cuticle removal filter, median filter, and morphological analysis in real-time mode could remove false positive errors. The ARS research groups and their industry partner are now merging the fecal detection and systemically disease detection systems onto a common platform using line-scan hyperspectral imaging system. This system will aid in commercialization by creating one hyperspectral imaging system with user-defined wavelengths that can be installed in different locations of the processing line to solve significant food safety problems. Therefore, the objective of this paper is to demonstrate the feasibility of line-scan hyperspectral imaging system in terms of processing speed and detection accuracy for real-time, on-line fecal detection at current processing speed of commercial poultry plant. The newly developed line-scan hyperspectral imaging system could improve Food Safety Inspection Service (FSIS)'s poultry safety inspection program significantly.

7676-20, Session 4

Development of real-time line-scan hyperspectral imaging system for online agricultural and food product inspection

S. Yoon, B. Park, K. C. Lawrence, W. R. Windham, G. W. Heitschmidt, USDA Agricultural Research Service (United States)

Hyperspectral imaging is a powerful imaging technique that can collect and process both spatial and spectral information of materials. In agricultural and food inspection applications requiring real-time online capture and processing, the use of line-scan hyperspectral imaging technology adopting a spectrograph has been limited at best. The development of a real-time line-scan hyperspectral imaging system has been hindered by the complexities of line-scan image acquisition and processing. Compared with area-scan cameras, this is largely due to the fact that line-scan hyperspectral imaging systems capture data one line at a time while most image processing algorithms require spatially coherent images to process. In addition, there is a lack of commercially available software that is capable of real-time acquisition and processing of data read out from an line-scan hyperspectral camera. From the hardware point of view, the challenge was to find the hardware platforms among many available platforms, suitable for the required application. From the software point of view, the challenge was to meet the processing-time requirements also determined by the application. In order to address the aforementioned issues, the USDA researchers developed an line-scan hyperspectral imaging system by adopting a hardware platform enabling the user to select non-contiguous discrete wavelengths and bandwidths so as to reduce the read-out time and by developing a C++ software platform enabling the image processing to be finished within the required time budget. The core of the software platform was based on a multitasking algorithm designed to enable simultaneous line capture and image processing. The developed imaging

system was evaluated in terms of resolution, speed, and quality of image processing. The line-scan hyperspectral imaging system is currently being developed and tested as a real-time online fecal detection tool for an industrial application.

7676-21, Session 5

Spatially resolved spectral scattering technique for assessing the total viable count of pork

Y. Peng, China Agricultural Univ. (China)

Spoilage in pork is the result of decomposition and the formation of metabolites caused by the growth and enzymatic activity of microorganisms. There is still no technology for the rapid, accurate and non-destructive detection of bacteria in spoiled or contaminated pork. In this study, hyperspectral imaging technique was exploited to measure biochemical changes within the fresh pork. Fresh pork samples were purchased from a commercial plant, and left to spoil in refrigerator at 8°C. Every 12 hours, hyperspectral scattering images over the spectral region between 400 nm and 1100 nm were collected directly from the sample surface in reflection pattern in order to develop an optimal model for prediction of the pork spoilage, in parallel with the total viable count (TVC) per gram of pork were obtained by classical microbiological plating methods. The spectral scattering profiles at individual wavelengths were fitted accurately by four-parameter modified Lorentzian and Gompertz functions. TVC prediction models were developed, using multi-linear regression, on relating individual Lorentzian and Gompertz parameters and their combinations at different wavelengths to log10(TVC) value. The Gompertz parameters had better prediction results with a correlation coefficient $r2> 0.90$ and a standard error of prediction (SEP) < 0.25 for log10(TVC). The research demonstrated that hyperspectral scattering technique is a valid tool for real-time and non-destructive detection of bacterial spoilage in pork.

7676-22, Session 5

Biophotonics determination of 6-Benzylaminopurine (6-BAP) plant growth regulator using OFRR biosensor

G. Yang, Rural Development Administration (Korea, Republic of)

The identification of pesticide and 6-benzylaminopurine (6-BAP) plant growth regulator was carried out using a label-free opto-fluidic ring resonator (OFRR) biosensor. The OFRR sensing platform is a recent advancement in opto-fluidic technology that integrates photonic sensing technology with microfluidics. It features quick detection time, small sample volume, accurate quantitative and kinetic results. The most predominant advantage of the OFRR integrated with microfluidics is that we can potentially realize the multi-channel and portable biosensor that detects numerous analytes simultaneously. Antisera for immunoassay were raised in rabbits against the 6-BAP-BSA conjugate. Using the immunization protocol and unknown cytokinin reacting with same antibody, comparable sensitivity and specificity were obtained. 6-BAP antibody was routinely used for cytokinin analysis. A sensitive and simple OFRR method with a good linear relationship was developed for the determination of 6-BAP. The detection limit was also examined. The biosensor demonstrated excellent reproducibility when periodically exposed to 6-BAP.

7676-23, Session 5

Development of highly sensitive handheld device for real-time detection of bacteria in food

K. Zhang, A. Zhang, L. Fu, B. A. Chin, Z. Cheng, Auburn Univ. (United States)

To ensure the safety of food, a detection device, which can detect/monitor the present of bacteria in a real-time manner and can be easily used for in-field test, is highly desirable. Recently, magnetostrictive particles (MSPs) as a new type of high performance biosensor have been developed. The detection of various bacteria and spores in the real food with high sensitivity has been experimentally demonstrated. To fully use the technique for food safety, a miniaturized interrogation system is needed to develop a handheld device. Both frequency and time domain techniques are exploited to develop the miniaturized interrogation systems, which are operated/controlled with a common laptop. The design principal and the characterization of the systems were presented. The real-time detection of the bacteria in liquid was performed using the systems. The systems have the capability to characterize multiple MSP sensors simultaneously, which provides a possibility for the detection of multiple targets using the MSP sensors simultaneously.

7676-24, Session 5

Wireless biosensors for detection of S. typhimurium in food products

B. A. Chin, S. Li, S. Huang, Z. Cheng, Auburn Univ. (United States)

Food-borne illnesses have garnered the attention of mainstream America with calls now coming from the media for more inspections to ensure the safety of our food supply. Annually approximately 80 million cases of food poisoning are reported in the United States alone. Food borne illnesses from the ingestion of S. typhimurium has been of primary concern due to its common occurrence in food products of daily consumption. Currently, the detection of bacteria in contaminated food relies on conventional microbiological methods that are time consuming and manpower intensive. This paper presents the results of a study to develop a phage-based magnetoelastic biosensor for the detection of Salmonella typhimurium. This affinity based biosensor is composed of a magnetoelastic resonator platform immobilized with filamentous phage as the bio-recognition element. A time varying magnetic field is used to oscillate the magnetoelastic resonator at its characteristic resonance frequency. The characteristic resonance frequency is dependent on the sensor dimensions and physical properties of the material. These sensors are of particular interest because they are wireless remote sensors, and therefore in-vivo detection in agricultural fields and closed containers is possible. The phage based biosensors for detection of S. typhimurium were characterized for specificity, dose response, detection limit and longevity. Detection limits of a few hundred cells per ml of liquid were measured with sensitivities of 1100 Hz/decade. The sensors maintained greater than 50% of their original binding affinity after being exposed to extreme storage conditions of 65℃ for 103 days.

7676-25, Session 5

Near-infrared microscopic methods for the detection and quantification of processed by-products of animal origin

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The Walloon Agricultural Research Centre (CRA-W) has been nominated in 2006 as community Reference Laboratory for the detection of animal proteins in feedingstuff (CRL-AP: http://crl.cra.wallonie.be). Since the BSE crisis, researches concern mainly the detection, identification, and quantification of meat and bone meal with an important focus on the development of new analytical methods.

The microscopic methods (NIR microscopy NIRM or/and NIR hyperspectral imaging) have been proposed as an alternative to the official method; optical microscopy. NIR spectroscopy offers the advantage of being rapid, accurate and independent of human analyst skills. The combination of an NIR detector and a microscope or a camera allows the collection of high quality spectra for small feed particles having a size larger than 50 µm.

Several studies undertaken have demonstrated the clear potential of NIR microscopic methods for the detection of animal particles in both raw and sediment fractions. In a first step of the development, samples are sieved and only the gross fraction (superior than 250 µm) is investigated. Chemometric models like Partial Least Squares (PLS) and Support Vector Machines (SVM) have been developed in order to determine the origin of the animal protein. The microscopic methods are efficient for the species specific detection of animal particles. Proposed methodologies have been developed to assure, with an acceptable level of confidence (95%), the detection of at least one animal particle when a feed sample is adulterated at a level of 0.1%. NIRM and NIR hyperspectral imaging are running under accreditation ISO 17025 since 2005 at CRA-W.

In a second step, a quantitative NIRM approach has been developed in order to fulfill the new requirements of the European commission policies. The capacities of NIRM method have been improved; only the raw fraction is analyzed, both the gross and the fine fractions of the samples are considered, and the acquisition parameters are optimized (the aperture, the gap, the influence of the contamination percentage, and the composition of the animal feed). A mapping method for a faster collection of spectra is also developed.

The aim of the work is to show the new advances in the analytical methods developed in the frame of the feed ban applied in the world.

7676-26, Session 6

Remote sensing of canopy dynamics and biophysical variables estimation of fodder crops

S. K. Rai, S. K. Das, A. K. Rai, Indian Grassland and Fodder Research Institute (India)

Optical remote sensing provides a powerful tool for monitoring and diagnosis of plant nitrogen (N) concentration status, which is necessary for site specific crop management. Leaf -N and chlorophyll (Chl) concentration of fodder crops are important indicators of plant N status. Studies were conducted to determine the relationship between canopy hyperspectral reflectance (325 to 1075 nm) and Chl or N concentration in field grown fodder crops [bajra (Pennisetum typhoides, sorghum (Sorghum bicolor L.) in Kharif season and oat (Avena sativa) in Rabi season] with and without recommended dose of nitrogen. Nitrogen fertilizer application mainly affected leaf reflectance at 575 and 623 nm in sorghum, 565 and 657 nm in bajra and 563 and 716 nm in oat. The reflectance ratio at R581/R397 (R2=0.46**), R619/R462 (R2=0.79***) and single reflectance at R542 (R2=0.53**) nm had the highest correlation with sorghum , bajra and oat leaf N concentration respectively. Similarly, sorghum, bajra and oat leaf Chl concentration were highly correlated with R677/R527 (R2=0.63**), R688/R409 (R2=0.71***) and R695 (R2=0.56**), respectively. The above ratios/single reflectance were used to estimate leaf N concentration of fodder crops (R2=0.44 to 0.78***). Similarly sorghum, bajra and oat leaf Chl could be best-estimated using reflectance ratio of R677/R527, R615/R411 and R695, respectively. Thus our results suggest that spectral reflectance measurements can be used for real time monitoring N status of fodder crops .

7676-27, Session 6

Comparative studies on drought monitoring application by remote sensing in winter wheat growing area of China

S. Li, Q. Wu, Chinese Academy of Agricultural Sciences (China)

Temperature Vegetation Drought Index(TVDI)and Vegetation Supply Water Index (VSWI)have been used widely for drought monitoring in recent years as they have clear physical significance and easy to be gotten. The former could be obtained by using periodical NDVI and LST product to construct Ts/NDVI space, and the latter could be got using periodical LST product divided by NDVI product, which is a simplified applicative index.

Winter-wheat-growing area of China has been used as research region in this paper, and EOS/MODIS data being used to construct those two indexes for drought monitoring during winter wheat growth in 2009, including six periods. Through analyzing about correlation between those two indexes and soil moisture in different depths, linear regression comparison and verification using ground data , conclusions have been drawn that both two indexes have better correlations with soil moisture in 10cm depth than that in 20cm depth, and TVDI has excellent correlation to soil moisture ,while VSWI not. As far as soil moisture being concerned for drought monitoring that TVDI surely perform better than VSWI, which could clearly reflect the tendency of regional drought. In addition, TVDI has stronger relativity to precipitation than VSWI.

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7677-01, Session 1

How far can distributed sensors go for the sensing length and the spatial resolution?

X. Bao, Univ. of Ottawa (Canada)

Distributed sensors have been explored with Rayleigh, Brillouin and Raman scattering for the temperature and strain sensing, the most strain sensing applications have been conducted with the Brillouin scatting based sensor for civil structural monitoring, such as bridges, dams, pipelines, and security associated applications. For the large infrastructural monitoring, long sensing is essential to cover large areas for conditional monitoring; while for local defects identification, high spatial resolution with high measurement accuracy is a key to identify the potential problem in early stages. However there is trade off in achieving long sensing length, high spatial resolution and measurement accuracy. In this talk, I will discuss the limiting factors for long sensing length, spatial resolution in distributed Brillouin sensors. Recent progress in various distributed sensors based on the transient Brillouin grating (TBG) of high spatial resolution, differential Brillouin gain of different pulse width pair (DPP) of long sensing length and optical parametric differential amplification (OPDA) for high measurement accuracy will be presented.

7677-02, Session 1

Distributed sensing for liquid leaks and spills

B. Culshaw, Univ. of Strathclyde (United Kingdom)

The detection and location of liquid spillage and leaks is needed in applications ranging from under water pipe lines and storage farms to district heating systems to laboratory clean rooms.

In this paper we shall describe a fibre optic based liquid detection system capable of locating a one metre spill over ranges to 10 kilometres. The system responds to hydrocarbon fuels, solvents and to water. The hydrocarbon systems are totally non responsive to the presence of aqueous solutions and vice versa. The system can distinguish between the two classes of fluids, a feature which shows promise in for example distinguishing between water ingress and oil leakage in sub sea and floating oil transportation and storage systems.

The basic principle embodies a cable incorporating a polymer which swells in response to the liquid of interest. The swelling drives an optical fibre against a microbend loss inducing structure and this loss is detected using optical time domain reflectometry. The very thin polymer layer - typically around 10 microns or less - responds rapidly from dry to wet states. Dependent upon the choice of polymer the system response is typically reversible but the speed of the relaxation process is dependent on the vapour pressure of the solvent. The relaxation can therefore take from seconds to many minutes.

We shall report recent advances in the design and realisation of this system. The basic building block is an optical fibre cable optimised to be sensitive to the changes in the thickness of the polymer component but insensitive to external bending and pressure induced influences on the cable itself. Our most recent designs additionally feature the ability to respond selectively to both classes of solvents and include, if appropriate, a reference channel within a single cable 3mm diameter structure.

We have characterised the response of a range of polymers to several solvents. Additionally we shall discuss the results of preliminary applications trials conducted to verify sensor performance.

7677-03, Session 1

Structural integrity and damage assessment of high-performance cable systems using an embedded distributed fiber optic sensor (EDIFOS) system

E. A. Mendoza, C. Kempen, Y. Esterkin, S. Sun, J. D. Prohaska, Redondo Optics, Inc. (United States); D. Bentley, Cortland Cable (United States); A. Glasgow, TMT Labs. (United States); R. Campbell, Applied Fiber (United States)

Redondo Optics is developing an embedded distributed fiber optic sensor (EDIFOS) system for the real-time, structural health monitoring, damage assessment, and lifetime prediction of synthetic material arresting gear cables. The EDIFOS system represents a new, highly robust and reliable, technology that can be use for the structural damage assessment of critical infrastructures. The Navy is currently investigating the use of new, all-synthetic-material arresting cables. This cable is one of the most stressed components in the arresting gear landing system. Synthetics offer higher performance in terms of the strength-to-weight characteristics, which improves the arresting gear engine's performance resulting in reduced wind-over-deck requirements, higher aircraft bring-back-weight capability, simplified operation, maintenance, supportability, and reduced life cycle costs. While employing synthetic cables offers many advantages for the Navy's future needs, the unknown failure modes of these cables remains a high technical risk. For these reasons, Redondo Optics is investigating the use of embedded sensors within the synthetic arresting cables to provide real-time structural assessment of the cable state, and to inform the operator when a particular cable has suffered impact damage, is near failure, or is approaching the limit of its service lifetime. To date, ROI and its collaborators have developed a technique for embedding multiple sensor fibers within the strands of high performance synthetic material cables and able to test the cable structures to tensile and compressive loads exceeding over 175,000-lbsf without any damage to the cable structure or the embedded fiber sensors.

7677-04, Session 2

Multifunctional sensor-embedded textiles for civil engineering applications

T. B. Messervey, D. Zangani, D'Appolonia S.p.A. (Italy); S. Casciati, Univ. of Catania (Italy)

Smart materials will be the building elements of tomorrow. These materials will employ sensors and actuators, will have communication capabilities, will contain self-healing agents, and other characteristics to make them multifunctional. As we progress toward this future, there are many challenges to identify and solve. Several include the integration of independent technologies into systems, the understanding and cooperation between multiple disciplines, the formulation of standards and guidelines, and the business case that convinces end users to adopt them.

One sector opportune for advancement and ready to lead this transition is that of technical textiles for civil construction. For the textile industry, such textiles provide a competitive advantage on the global market and open a door into the largest industry in the world, civil engineering. For civil engineers, technical textiles provide one product that serves two common purposes, reinforcement and monitoring. The value of multi-functionality is worth noting. Clients typically reject multiple independent solutions to accomplish a task. In contrast, clients are likely to accept a single solution that may have a higher cost, but provides exceptional value.

This paper will highlight four years of research toward the realization of multifunctional technical textiles for masonry and geotechnical applications. Mostly through the warp-knitting of fibre optic sensors in polymer, glass, and carbon meshes, these products provide the engineer with a tool to conduct structural health monitoring while increasing the strength, ductility, and safety of the structure they are integrated with. Highlighted case studies will include masonry retrofit and subsequent seismic testing, the monitoring of slope stability failures along road embankments, the monitoring of soil slumping at closed mining areas, and the chemical monitoring of landfills.

7677-05, Session 2

Protection of critical infrastructure using fiber optic sensors embedded in technical textiles

K. Krebber, Bundesanstalt für Materialforschung und -prüfung (Germany)

Invited Talk proposed by Dr. A. Mendez:

Terrorists and criminals more and more attack and destroy important infrastructures like routes, railways, bridges, tunnels, dikes and dams, retaining walls, electric and nuclear power plants, radioactive waste deposits, pipelines. Therefore, reliable on-line and long-term monitoring systems are required to protect such critical infrastructures. Fiber optic sensors are well-suited for that. They can be installed over many kilometers and are able to measure distributed or quasi-distributed strain, pressure, temperature, nuclear radiation and further mechanical and physical quantities. The very tiny optical fibers can be integrated into structures and materials and can provide information about any significant changes or damage of the structures. These so-called smart materials and smart structures are able to monitor itself or its environment.

Particularly smart technical textiles with embedded distributed fiber optic sensors have become very attractive because of their high importance for the structural health monitoring of geotechnical and masonry infrastructures. Such textiles are usually used for reinforcement of the structures and the embedded fiber optic sensors provide information about the condition of the structures and detect the presence of any damages and destructions of the structures in real time. Thus, critical infrastructure can be preventively protected. Europe has driven substantial developments in distributed fiber optic sensing and technical textile technologies for the above mentioned monitoring purposes by a number of research projects. The paper will introduce this innovative field and will present the results achieved within the research projects using different fiber optic sensing techniques like distributed Brillouin sensors, distributed POF sensors and FBG sensors.

7677-06, Session 2

Robust event classification for a fiber optic perimeter intrusion detection system using level crossing features and artificial neural networks

S. Mahmoud, J. Katsifolis, Future Fibre Technologies Pty Ltd. (Australia)

All outdoor fence-based perimeter intrusion detection systems are susceptible to a wide range of nuisance alarms from both environmental and man-made sources. A critical performance parameter of any outdoor perimeter intrusion detection system is therefore its capability of discriminating between intrusion and nuisance events without compromising sensitivity or probability of detection. This is especially challenging for intrusion and nuisance events which may have a similar impact on the perimeter fence or similar signal features. The key to overcoming this challenge is to carefully choose the right combination of features or signatures within the event signals to formulate an effective and robust real-time event classification system. In this paper, a robust event classification system using features based on level crossings is presented for the detection and recognition of intrusion and non-intrusion events in an outdoor fence-mounted intrusion detection system for a range of operating environments and fence styles. The proposed classification system is applied to a fence-mounted distributed fiber-optic Mach Zehnder and consists of a pre-processing stage employing high resolution time-frequency distribution, a novel event detection and feature extraction scheme based on level crossings, and a classification algorithm using a supervised neural network. Experimental results are presented showing accurate classification of different intrusion and non-intrusion events such as fence-climbing, fence-cutting, stone-throwing and stick-dragging. These results demonstrate the robustness of the proposed algorithm for various types of fence fabric and operating environments.

7677-07, Session 2

Component field testing for SWPIDS: a shallow-water perimeter intrusion detection system

D. Burnett, D. A. Sheaffer, Jr., Sandia National Labs. (United States)

Performance testing of three commercial off-the-shelf fiber-based security sensors over several months in a shallow-water marine environment is presented. This paper gives an overview of the three sensors, a description of how each sensor was tested for performance in an active marine environment, and the results of testing, including basic functionality, nuisance alarm rates, and environmental effects. Behavior and longevity over longer time scales is predicted. Sensors tested include a breach-sensitive stainless steel grate containing fiber cable which breaks when the fence is cut, and a magnetic tamper switch which restricts light flow through a fiber when removed from the presence of a metal object, both from Woven Electronics. Also included is a heavy-duty buried fiber cable typically used for sensing terrain disturbances by FiberSenSys, LLC. Preliminary results from ongoing tests indicate all three products are highly resistive to the destructive forces present in a marine environment and continue to function with low nuisance alarm rates. After presenting testing results, a method is proposed to combine these sensors into a high-security, low-nuisance alarm, environmentally-friendly underwater barrier capable of sensing most attempts at penetration or circumvention.

7677-08, Session 2

Positioning method for dual Mach-Zehnder interferometric submarine cable security system

S. Xie, Tsinghua Univ. (China); Q. Zou, D. Tu, Ningbo Nuoke Electronic Technology Development Co., Ltd. (China); M. Zhang, S. Lai, Y. Liao, Tsinghua Univ. (China)

Event positioning algorithm plays an important role in the application of dual Mach-Zehnder (MZ) interferometric perimeter security system. By using cross correlation time delay estimation, the accuracy is mainly constrained by the bandwidth of the signal according to Cramer-Rao lower bound (CRLB). Especially in some perimeter security system cases, e.g. application in buried or submarine cable, the earth or the cable itself forms a low pass (LP) system which makes the bandwidth of detected event signal quite narrow (several hundred Hz). The existing revised cross correlation time delay estimation algorithm can not deal with this situation properly. A preprocessing method focusing on effectively widening event signal bandwidth before correlation is proposed here. A high pass filter (HPF) with proper cutoff frequency is imposed to original signal to suppress low frequency components which lead to large estimation errors and to strengthen the effect of high frequency components, despite the filtered signal is totally different from the input. A procedure of determining optimal cutoff frequency of HPF is put forward with

considering the SNR of signal. Simulation and experiment results show great coincide with theory.

7677-09, Session 3

Review of high-speed fiber optic grating sensor systems

E. Udd, Columbia Gorge Research (United States); J. J. Benterou, Lawrence Livermore National Lab. (United States)

High speed fiber optic grating sensor can be used to support nondestructive evaluation of composite materials, monitor traffic on highways and bridges, track position and velocity during detonations and aid high speed machining operations. This paper will provide an overview of a series of fiber grating sensor systems to support these applications.

7677-10, Session 3

Structural health monitoring (SHM) of primary aircraft structures impact location (damage) detection, vibration, and load monitoring

T. van Els, Technobis Fibre Technologies (Netherlands)

Abstract:

The increasing use of thermoplastic carbon fibre reinforced plastic (CFRP)materials in the aerospace industry for primary aircraft structures has lead to a rapid growth in the field of SHM.

One of the failure mechanisms of composite materials is de-lamination resulting from impact, vibration and load. The de-lamination of the material can occur without being visible to the human eye. This makes inspection of, and clear insight into the structural integrity difficult by using currently standard inspection methods.

This paper will elaborate on the detection of impact, its localization and its potential damaging effects on the material/structure by using high speed interrogation of multiple Fibre Bragg Grating (FBG) sensors mounted on/embedded in a composite aircraft component. A test setup has been developed. This setup consist of a composite aircraft component with FBG sensors that are connected to the light weight, small size, high speed Deminsys interrogator and a data acquisition and management system. The test setup provides real-time feedback on impacts and the material's condition.

7677-11, Session 3

A novel twin-core fiber grating sensor system and its applications

Y. Li, G. M. Bubel, D. Kudelko, M. F. Yan, M. J. Andrejco, OFS (United States)

We demonstrated a novel twin-core fiber grating sensor system for simultaneous measurements of temperature and strain. In fiber gratings for temperature and/or strain sensor applications, one must either decouple all parameters affecting the grating wavelength or isolate individual parameters to obtain the measurement of interest. Our novel twin-core fiber grating sensor system addresses the decoupling and isolation issues. Specifically, we designed two cores with custom index and dopant profiles such that the gratings in these two cores have different temperature coefficients (12.1pm/C and 13.5pm/C at 200^oC), but almost same strain coefficients (1.120pm/microstarin and 1.104pm/microstrain). These distinct coefficients enable simultaneous and accurate measurements of temperature and strain experienced by the sensor. Our data also show that wavelength shifts in both gratings are almost the same from one Deuterium concentration level to another in the fiber. This, together with the strain characteristics, enables us to isolate the temperature measurement when both strain and some

gaseous diffusion also exist; and this makes our grating sensor extremely useful for hydrothermal down-hole temperature mapping applications. Furthermore, we show that the fiber tapering technique can be employed to create a coupling region directly in the twin-core fiber such that we can measure both gratings in the two cores simultaneously.

7677-12, Session 3

Fiber Bragg grating accelerometer for multi-axis sensing applications

S. Ferguson, Micron Optics, Inc. (United States); A. Cigada, L. Comolli, Politecnico di Milano (Italy); A. Mendez, MCH Engineering LLC (United States)

Over the last few years, optical fiber sensors have seen an increased acceptance as well as widespread use in structural sensing and monitoring in civil engineering, aerospace, marine, oil & gas, composites and smart structure applications. Although strain and temperature sensors are more frequently developed and introduced as commercial products, more and more, many industrial and structural health monitoring applications demand the use of accurate, sensitive, EMI immune and environmentally-hardened accelerometers and vibration sensors.

In this paper, we report the design and development of a novel accelerometer based on the use of an optical fiber Bragg grating (FBG) mounted into a custom-made miniature, deflection beam. The FBG element is attached using a special bonding technique. The optical fiber sensing element and micro-mechanical inertial transducer are packaged inside a miniature, rugged, and sealed metallic housing. The device displays a linear, flat response from 0 to 400Hz, with an adjustable peak resonance frequency in the 700 to 1,000Hz range. The accelerometer is a single-ended, single axis device, which can be combined with one or two more sensors to form 2 and 3 Axes accelerometer sensors. Pertinent test data will be presented describing the sensor's vibration response and environmental stability.

7677-13, Session 4

Self-heated fiber Bragg grating sensors for cryogenic environments

P. R. Swinehart, M. S. Maklad, Lake Shore Cryotronics, Inc. (United States); T. Chen, M. P. Buric, K. P. Chen, Univ. of Pittsburgh (United States)

Cryogenic fuels, such as liquid hydrogen, oxygen, and liquefied natural gas, are often considered as major energy alternatives to augment or replace coal and petroleum based fuels. To ensure safe storage and transfer of liquefied fuels, safe and reliable sensor networks are required for on-demand, real-time fuel management in cryogenic environments.

Fiber Bragg gratings (FBG) are key components for optical sensing. However, FBG sensor sensitivity degrades rapidly due to the diminishing thermal-optical coefficients of silica glasses at low temperature.

In this paper, a new sensor design is described that enhances the low-temperature performance of fiber sensors. FBGs inscribed in high attenuation fiber (HAF) are used to absorb in-fiber power light to raise the local sensor temperature in the cryogenic environment. When in-fiber power light is turned off, FBG sensors can serve as passive sensors to gauge temperature and stress in the cryogenic system. When the in-fiber power light is turned on, the heated sensors can be used to rapidly gauge fuel level and fuel leaks.

In one example, a hydrogen gas sensor is demonstrated with a palladium-coated fiber Bragg grating (FBG). The low-temperature performance of the sensor was improved by heating the gratings as much as 300 K above the ambient temperature, and hydrogen concentration well below the 4% explosion limit was measured at 123K. In a second example, an array of four aluminum coated fiber Bragg gratings was used to measure liquid level in a cryogenic environment.

7677-14, Session 4

High-temperature fiber Bragg grating sensors in microstructured fibers for harsh environment applications

C. M. Jewart, Q. Wang, Univ. of Pittsburgh (United States);
J. Canning, The Univ. of Sydney (Australia); S. J. Mihailov, D. Grobnic, Communications Research Ctr. Canada (Canada); K. P. Chen, Univ. of Pittsburgh (United States)

Pressure sensors operated at high temperature have many important applications in the energy industry. They ensure safe and efficient energy production during operations of gas turbines, coal boilers, nuclear power plants, and others. The high temperature environment presents unique challenges to sensing systems. It not only requires robust sensor elements but also demands reliable packaging and wiring techniques rated for the high temperature harsh environments.

In this paper, we present fiber Bragg grating pressure sensors in air-hole microstructured fibers for high temperature operation above 800°C. Both an ultrafast laser writing technique and a regenerative grating writing techniques were used to produce high-temperature stable fiber Bragg gratings in air-hole microstructure fibers for pressure sensing. The fiber Bragg grating resonance wavelength shift and peak splits were used to gauge external hydrostatic pressure from 15 psi to 2000 psi.

This work demonstrates a significant improvement of the operational temperature of FBG pressure sensors in air-hole microstructured fiber to over 800°C. A large number of high-temperature FBG pressure sensors in microstructured fibers can be massively produced in one fiber using a simple phase mask technique. The multiplexed fiber sensor array in a single fiber can be serviced by a single reading system using a single fiber feedthrough, which will dramatically reduce the wiring complexity of a sensor network for high-temperature applications.

7677-15, Session 4

Regenerated fiber Bragg gratings in non-hydrogen-loaded photosensitive fibers for high-temperature sensor networks

E. Lindner, S. Brueckner, IPHT Jena (Germany); C. Chojetzki, FBGS Technologies GmbH (Germany); M. Becker, M. Rothhardt, H. Bartelt, IPHT Jena (Germany)

We report about a thermal regeneration of fiber Bragg gratings written in photosensitive fibers without hydrogen loading and with the use of UV nanosecond laser pulses. We observe a complex regenerative process which indicates a secondary grating growth in an optical fiber by thermal activation. This process leads to an increased temperature stability of the gratings up to 600 °C which differs from the commonly known Type I gratings. With the use of an interferometric writing technique it is possible to generate arrays of regenerated fiber Bragg gratings (RFBGs) for sensor networks. The writing conditions of such new type of grating are investigated and the temperature behavior of these RFBG is analyzed. This type of gratings is suitable for high temperature sensor networks, combining the attributes of good spectral shape and high reflectivity with high temperature stability showing no drift or hysteresis.

7677-16, Session 4

Liquid level sensor based on fiber Bragg grating and carbon fiber composite diaphragm

D. Song, J. Zou, Z. Wei, H. Cui, Stevens Institute of Technology (United States)

A novel liquid level sensor based on and fiber Bragg grating and carbon fiber laminate diaphragm is proposed in this paper. The sensor system consists of separating diaphragm, section housing and carbon fiber laminate diaphragm bonded with fiber Bragg grating. Pressure affects separating diaphragms and oil fill, creating internal pressure in central section which deflects the sensor diaphragm. As a result, it induces the Bragg wavelength shift. In this paper, the sensing principle and finite element analysis are presented. From the experimental result, this sensor shows high sensitivity and good repeatability

7677-17, Session 4

Analysis of temperature and strain changes profiles by using fiber Bragg grating sensors

M. Etezad, M. Kahrizi, K. Khorasani, Concordia Univ. (Canada)

The sensor industry has witnessed an extensive research activity on the use of ultra violet (UV) inscribed in fiber grating sensors. This class of sensors have many advantages over conventional sensors. They are light weight, immune to electromagnetic wave interference and have the capability to be multiplexed in a large number which makes them ideal candidates for in-situ health monitoring and diagnostics of composite materials. These sensors are also fairly inexpensive due to high demands for fiber Bragg grating (FBG) devices in the telecommunication industry.

In addition to the characteristics above, the reflected spectrum of the fiber Bragg grating sensor (FBG) is sensitive to temperature and strain changes in a way that it can be used as a temperature or strain sensor when placed on or inside the substrate. The reflected spectrum of the FBG sensor can be determined directly by using the T-matrix method. On the other hand, the strain distribution in the FBG can be obtained from its own reflected spectrum. This approach is known as the inverse approach, which is based on calibrating the parameters of a mathematical model to reproduce observations. Several inverse methods have been proposed in the literature for reconstructing the grating parameters from its corresponding reflected spectrum. Fourier-transform, Gelfand-Levitan-Marchenko (GLM) and layer peeling algorithms are among these methods. However, these methods require both the phase spectral as well as the amplitude spectral in order to solve the inverse problem which results in rather complex setup configurations. Optimization methods, such as the simulated annealing (SA) and Genetic algorithms (GA), can retrieve the grating parameters based on only the amplitude spectral. However, the simulated annealing method has the tendency to become slow when the number of parameters increases. In this paper, we propose to use genetic algorithms for implementing and developing our inverse approach. We first calculate the reflection spectrum of a single FBG sensor and a series of ten FBG sensors that are subjected to temperature or strain perturbations. Subsequently, by using genetic algorithms, the FBG parameters that include the chirped gratings along the sensor and the refractive index modulations are synthesized.

To summarize, this paper has proposed an arbitrary strain distribution sensing approach by using the genetic algorithm to inversely trace the strain distribution from a series of 10 sensors measured from their reflected spectrum that was obtained by using the T-matrix method. In addition to locating the place of an applied strain by using an FBG WDM sensor network, we were able to estimate the shape and severity of the strain. The feasibility of our proposed method has been demonstrated by solving the inverse problem by using the genetic algorithm for one sensor that is subjected to an arbitrary strain change and developing and implementing the inverse method to a series of an WDM FBG sensor network consisting of ten sensors. By increasing the number of divided sections and wavelength sample points one can minimize the error between the measured and the calculated spectra from GA, at the expense of longer simulation times which is an important issue and consideration for real-time health monitoring. Nevertheless, further work is required to perform improved optimization of the GA parameters. Furthermore, in our future work our goal will be to utilize the refractive index profiles that are obtained for a sensor subjected to both temperature and strain changes to allow one to discriminate between the temperature and the strain stimuli.

7677-18, Session 5

Research and application of FBG safety monitoring methods used for huge structures and equipments

D. Jiang, K. Che, C. Zhou, J. Huang, D. Fan, Wuhan Univ. of Technology (China)

Abstract: Fiber optic sensing technology has a number of special advantages and has played an important role in many fields. Since there would be a lot of information in the monitoring process of huge structure engineering, many kinds of sensors with excellent long-term stability will be needed. However, the sensing signals of huge equipments especially the rotating machinery equipments can not be transmitted through optic fiber in the line transmission way. Furthermore, for the fiber optic sensing technology used for the detection of huge structures and equipments, a lot of technology problems of engineering application need to be solved. At present, the products of fiber optic sensors used in actual engineering are very limited.

In this paper, the typical problems in the engineering application of fiber optic sensing technology in the safety monitoring of huge structures and equipments have been analyzed, and its key technologies have been studied, including FBG detecting technology in harsh environment and the environments with high temperature and huge strain, the multipoint monitoring technology with huge capacity, and the demodulating technology. On that basis, several kinds FBG sensing methods and products used for the safety monitoring of huge structures and equipments have been successfully developed. The application examples of these products in the safety monitoring of a number of huge structures and equipments such as bridges, tunnels, rotating machinery and oil tanks have been presented. The typical effects to monitor the hidden trouble of safety and prevent the accidents from extending with these FBG sensing systems have been reported, which would be helpful for solving the related technical problems in these fields.

7677-19, Session 5

The design of strain rosette on fiber Bragg grating and carbon fiber laminate composite

D. Song, J. Zou, D. Li, H. Cui, Stevens Institute of Technology (United States)

fiber Bragg grating is often used in strain sensing,especially where environment is harsh. In this paper, a strain rosette based on fiber Bragg grating and carbon fiber laminate composite is proposed.carbon fiber laminate composite is a novel composite designed by us. The fiber Bragg grating is embedded in carbon fiber laminate composite to function as strain sensor.Three these kinds of strain sensor are arrenged in a rosette configuration to assess the in-plane strain.

7677-20, Session 5

Non-intrusive FBG tube pressure transducers with high overpressure ability

I. F. Saxena, K. J. Hui, Intelligent Optical Systems, Inc. (United States)

Fiber optic sensors offer several advantages over their electrical counterparts especially for hostile, spark-sensitive environments as no electrical power is required at the sensors. This paper characterizes the application of fiber Bragg grating (FBG) sensors for non-intrusive, remote, monitoring of pressure in various types of metallic tubing. Measuring pressure-induced expansion, these fiber sensors can be installed external to fluid carrying conduits (unlike in-line diaphragm based sensors) facilitating troubleshooting and replacement. Furthermore, glass fiber pressure sensors have a much higher operating temperature range for flammability-prone environments. Several FBG sensors can be multiplexed along a single fiber optic cable, achieving multipoint pressure monitoring with far less complexity than that required for traditional electronic pressure sensors. These fiber-optic pressure detection systems have a wide variety of potential applications, including noninvasive monitoring of flow in fuel lines and internal pressure in valves. We show that these FBG sensors can measure internal pressure changes with a few psi resolution on 1 inch diameter tubes using tunable diode laser based detection. Standard metal pipes of steel, inconel, copper-nickel alloy and titanium are characterized, and resilience to an overpressure up to 1500 psi is demonstrated.

7677-22, Session 6

What laser source technology is the most adequate to fuel stellar defense, security, and sensing industry boost?

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Fiber-optic sensing system for Defense and Security applications feel necessity for laser sources. These system's work environments are more demanding than ever, increasingly crossing the limit of comfort of fiber laser technology. Narrow linewidth semiconductor laser technology features a small footprint and low power consumption as well as unmatched robustness and reliability. When properly packaged, these lasers also display an unrivalled immunity to vibrations and acoustic noise. These features are all required for Defense / Security fiber-optic sensing applications. These systems operate in harsh environments or in rooms contaminated acoustically by electro-mechanical equipment.

The present paper will discuss past and future developments towards the size reduction of acoustically isolated narrow linewidth semiconductor lasers. A low complexity package involving few optical components translates into a lower cost and improved long term reliability for end users. Techniques implemented to reduce the high-frequency phase-noise while leveraging the great intrinsic relative intensity noise performance of these sources will be reviewed. Means to increase the noise reduction bandwidth will be discussed. Simulation results of interferometric sensing systems will also be presented, taking into account both the intensity and phase noise of the laser. It will be shown that narrow linewidth semiconductor lasers can outperform fiber lasers, especially in applications where a good control over the differential delay of the sensing interferometer is afforded.

7677-24, Session 6

Technologies of fiber fusion and fused device fabrication for fiber sensing applications

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Fiber technologies, including Fiber Bragg Grating, fiber Brillouin and Raman scattering, have been widely used for variety of discrete and distribute sensing applications such as temperature, strain, and acoustic wave measurements. In addition, tapered fiber device and small diameter fiber (or nano fiber) possess some special fiber waveguiding property, which enables environmental sensing. Fabrication of fused fiber component and fusion splicing between different fibers and devices are critical for enabling fiber sensing technology and building reliable and high performance fiber sensing systems. In this paper, we review the fiber fusion and fused component technologies, describe fundamental optics, and discuss key optical requirement for such systems. In addition, we describe how these fiber glass processing technologies are applied to the fiber sensing systems. We will also show some application examples and describe some hardware that high quality fiber handling and processing.

7677-25, Session 6

Implementation of fiber filters based on a macrobending high-bend loss fiber utilizing the whispering gallery mode effects

P. Wang, Y. V. Semenova, G. T. Farrell, Dublin Institute of Technology (Ireland)

Optical filters have been used for a wide variety of applications in many optical systems, such as dense wavelength division multiplexed (DWDM) systems, optical test instruments, and optical fiber sensing devices, to reject unwanted frequency/wavelength components from the source signal or to select and enhance the desired ones. Among different optical filter types, an optical fiber filter, for example a fiber Bragg grating based filter [1, 2], has a simple configuration that uses the transition region of the FBG transmission response to block optical powers of desired wavelengths or to equalize a transmission spectrum.

The WGM effect caused by the interference occurring in the bare macrobending fiber has been studied recently and a bending fiber utilizing WGM has been demonstrated for use as a novel optical sensing device, e.g., displacement sensor [3] and temperature sensor [4]. These optical devices based on a macrobending fiber structure offer all-fiber solutions for optical sensing with the advantages of ease of fabrication compared with FBG based filters and connection to conventional optical fiber systems.

For a bare bending fiber, a notch filtering feature [3] has been demonstrated by tuning the fiber bending diameter. In this paper, a brief description of the basic principles of the WGM effect in bending fiber is presented and an overall experimental demonstration of spectral responses of the bending fiber based filters utilizing the WGM effect has been carried out and is investigated.

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7677-26, Session 7

Review on developments in fiber optical sensors and applications

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The last couple of decades had witnessed a rise in research of optoelectronic and fiber optical communication fields, which resulted in applications focused initially in military and aerospace equipments, and later in health monitoring for medicine, heritage culture and various engineering fields. The monitoring of existing or /and new engineering, biomedical structures has become a regular feature throughout the world and is fast emerging as a pioneering field. This field is very vast, consisting of traditional monitoring methods as well as smart system based methods. The fiber optics belong to finest class of smart materials, there are many types and classifications of fiber optics based on necessity, manufacturer and the end user. In this paper, a complete over view of fiber sensing systems and their usefulness is presented.

7677-27, Session 7

In-situ dynamic measuring system to measure the vibratory and translational displacement of the airfoil modes of a combustion turbine compressor vane via an optical noncontact method

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An in-situ Dynamic Measuring System is developed and tested to measure the vibratory and translational displacement of the airfoil modes of a combustion turbine compressor vane via an optical non-contact method. The Dynamic Measurement System measures the dynamic contact displacement in the radial direction of the combustion turbine, which can be implemented as measurement of radial displacement on the axial contact surface. The dynamic system is a non-contact device that uses a fiber optic bundle (FB) for the sensor element probe. The probe is placed in proximity of the target area. Motion of the target is determined by the amount of light received by the probe. The fiber bundle system is capable of simultaneous measurement of vibratory (AC) motion and free body or translational (DC) motion. The AC modes are resolved spectrally by an FFT of the raw FB signal. The FB correctly identified the modes and their associated magnitude on the airfoil and measured the displacement of the target area.

7677-28, Session 7

Intrinsic Fabry-Perot interferometric (IFPI) fiber sensor for quasi-distributed pressure sensing

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An optical fiber Single-mode/Multimode/Single-mode Intrinsic Fabry-Perot Interferometer (SMS-IFPI) sensor was hermetically sealed in a pressure transducer by CO_2 laser fusion bonding. The transducer is formed by bonding the Fiber with two glass Ferrules and a glass Tube (FFT), the whole structure is made of fused silica in order to work at environmental temperatures as high as 600 ºC. The extremely low transmission loss of the SMS-IFPI sensors makes them suitable for multiplexing in a single optical fiber link. We applied a spectrum measurement system and a frequency-division-multiplexing (FDM) scheme based on a frequency modulated continuous wave (FMCW) technique in which multiple IFPI sensors with different cavity lengths can be interrogated along a single fiber and the optical path difference (OPD) of each sensor can be monitored separately. We achieved quasi-distributed pressure sensing at high temperature based on the FFT-bonded SMS-IFPI sensor.

7677-29, Session 7

Chiral fiber sensors

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Chiral fiber sensors are helical structures implemented in optical fibers. We have fabricated a variety of chiral sensors by twisting one or more conventional or custom optical fibers with noncircular or nonconcentric core as they pass though a miniature oven. The resulting structures are as stable as the glass material and can be produced with helical pitch ranging from microns to hundreds of microns. The geometry of the fiber cross section determines the polarization selectivity of the

chiral gratings. Single helix structures are polarization insensitive while double helix gratings interact only with a single optical polarization. Both single and double helix gratings may function as a fiber long period grating, coupling core and cladding modes or as a diffraction grating scattering light from the fiber core. The resulting spectral features seen as dips in the transmission spectrum are sensitive to fiber elongation, twist and temperature, and (in the case of the long period gratings) to the refractive index of the surrounding medium. The suitability of chiral gratings for sensing temperature, elongation, twist and liquid levels will be discussed. Gratings made of radiation-hardened glass are suitable for stable operation in nuclear power plants, while gratings made of radiation sensitive glass can be used to measure the cumulative radiation dose. Excellent temperature stability up to 1000 C is found in pure silica chiral diffraction grating sensors.

7677-30, Session 8

Ultrasound interferometric plastic optical fiber (POF) sensors for biomedical applications

H. R. Lamela, D. C. Gallego, Univ. Carlos III de Madrid (Spain)

Ultrasound imaging is a non-invasive technique that achieves high resolution (10-50 μm), by using high ultrasonic frequency (10-100 MHz). These features make it suitable in many medical imaging applications. The detection technology used is typically based on piezoelectric materials, however such sensors present difficulties which are related to the element size, and this prevents their use with high ultrasonic frequencies, which are necessary in most medical diagnosis applications. Using optical techniques has many advantages over traditional electrical methods such as, large detection bandwidth (100 MHz), immunity to electrical and mechanical perturbations and the possibility of higher resolution

In this paper, a Plastic Optical Fiber (POF) ultrasound interferometric sensor will be performed for the first time to our knowledge which demonstrates a much higher sensitivity compared to Silica Fiber interferometric sensors. In this work, a comparison between these two different fiber optic interferometric ultrasonic sensors will be performed for Optoacoustic Biomedical Imaging (1 MHz-100 MHz). This will be done based on the comparison of sensitivity, dynamic range, frequency bandwidth, spatial resolution and compactness.

7677-31, Session 8

Dynamic test of an acoustic/pressure sensor with precise cavity length control

W. Wang, N. Wu, Y. Tian, R. Liu, C. Guthy, X. Wang, Univ. of Massachusetts Lowell (United States)

A novel Fabry-Pérot interferometer pressure/acoustic sensor has been designed, fabricated, and tested. The sensor consists of an angle-polished fiber, a V-shaped groove on a silicon substrate, and a silicon nitride diaphragm on the side wall of the groove. The design takes advantage of MEMS technology to ensure cavity length control and flexibility of the diaphragm design. Two tests were performed on the sensors. The first was a shock test, where a balloon was popped near the sensors. The second used a shock tube to simulate a blast event. Multi-sensor assemblies, where all the sensors were calibrated to have similar center wavelengths, were also put together. The assemblies were tested simultaneously using a single laser source. The results of all these tests show that the performance of the Fabry-Pérot sensors closely matches that of the reference sensors used.

7677-32, Session 8

Theoretical analysis of a novel ultrasound generator on an optical fiber tip

N. Wu, W. Wang, Y. Tian, C. Guthy, X. Wang, Univ. of Massachusetts Lowell (United States)

A novel ultrasound generator consisting of a single mode optical fiber with a layer of gold nanoparticles on its tip has been designed. The generator utilizes the optical and photo-acoustic properties of gold nanoparticles. When heated by laser pulses, the thin absorption layer made up of these nanoparticles at the cleaved surface of a single mode fiber generates a mechanical shock wave caused by thermal expansion. Mie's theory was applied in a MATLAB simulation to determine the relationship between absorption efficiency and optical resonance wavelengths of a layer of gold nanosphere. Results showed that the absorption efficiency and related resonance wavelengths of gold nanosphere varied based on the size of the gold nanosphere particles. In order to obtain the bandwidths associated with ultrasound, another MATLAB simulation was run to study the relationship between the power of the laser being used, the size of the gold nanosphere, and the energy decay time. The results of this and the previous simulation showed that the energy decay time is pico-seconds in length.

7677-33, Session 8

Simulation of a novel ultrasound generator-receiver on a single optical fiber

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A novel ultrasound generator-receiver built on a single-mode optical fiber using a layer of gold nanoparticles has been designed. The generator is based on the optical and photo-acoustic properties of gold nanoparticles. Thermal and pressure waves are generated in the nano-particle layer when it is exposed to high intensity, short duration laser radiation. The laser radiation is applied in an intensity range that creates an instantaneous surface heating of the layer material that, in turn, drives a pressure wave into the layer. The pressure wave interacts with the layer-substrate interface to create stress distributions of varying strengths and qualities, depending on the intensity and duration of the initial laser pulse. The radiation due to laser-induced heating on the nano-particles was investigated using FEA analyses. The maximum principal stress distribution was investigated by the FEA. Results indicate that the ultrasound generation elements have almost zero effect on the diaphragm.

7677-34, Session 9

Photonic crystal fiber as a full-length surface-enhanced Raman scattering optofluidic platform

Y. Han, M. K. Khaing Oo, S. A. Sukhishvili, H. H. Du, Stevens Institute of Technology (United States)

The unique feature of photonic crystal fiber (PCF) both as a light guide and a liquid transmission cell allows synergistic integration of optics and microfluidics to form an unconventional optofluidic platform of long interaction path limited only by the fiber length. We report the strategy and methods in realizing full-length surface-enhanced Raman scattering (SERS) PCF optofluidics by polyelectrolyte-mediated immobilization of Ag nanoparticles inside the fiber air channels. Through forward propagating Raman measurements and hyperspectral Raman imaging, we show that

SERS-active PCF optofluidics can be achieved with accumulative Raman signal gain along the entire fiber length when nanoparticle-induced attenuation is managed through low coverage density (typically < ~0.5 particle/μm2) of Ag nanoparticles. Under such controlled conditions, we demonstrate SERS measurements of 1x10-7 M or ~48 ppb Rhodamine 6G in a minute ~10-7-10-8 liter aqueous solution using over 20 cm PCF. The combination of high detection sensitivity and small sampling volume renders the SERS-active PCF optofluidic platform excellent potential for a multitude of applications ranging from label-free chemical and biological identification to process monitoring in geometrically confined systems.

7677-35, Session 9

Design, fabrication, and optical characterization of highly sensitive refractometers based on all-polymer liquid-core photonic bandgap Bragg fibers

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We present design principles, fabrication strategies, and optical characterization of the resonant refractive index sensors that use all-polymer photonic bandgap Bragg fibers filled with liquid analytes. Low refractive index-contrast Bragg fibers have narrow bandgaps whose spectral positions are highly sensitive to the value of the real part of the analyte refractive index filling the fiber core. We first demonstrate theoretically that when Bragg fiber is operated in the radiation loss dominated regime it can be used as a highly sensitive sensor of changes in the real part of the analyte refractive index. Moreover, sensitivity of such sensors is shown to be comparable to that of the waveguide-based plasmonic sensors, with theoretical sensor resolutions as high as 10-5 RIU. We also find that maximal attainable sensor sensitivity is largely independent of the fiber length. Therefore, very compact sensors made of just several cm long Bragg fiber can be demonstrated. Finally, we present experimental measurements of the sensor sensitivities using water-filled and oil-filled cores.

7677-36, Session 9

Mode coupling in photonic crystal fiber using long-period gratings for enhanced overlap of evanescent field

Z. He, Y. Zhu, Stevens Institute of Technology (United States); J. Kaňka, Institute of Photonics and Electronics of the ASCR, v.v.i. (Czech Republic); D. J. Trevor, OFS (United States); H. H. Du, Stevens Institute of Technology (United States)

Excitation of cladding modes has been achieved using long-period gratings (LPGs) inscribed in an endlessly single-mode photonic crystal fiber (ESM PCF) by CO2 laser irradiation. Core-cladding mode coupling and recoupling has resulted in marked improvement in the evanescent field overlap throughout the cladding air channels in the PCF-LPG structure, compared to PCF alone. Our numerical simulation has shown that optimization of the PCF-LPG configuration can lead to a field power overlap as high as 8.05% for gas and 22.3% for liquid with a confinement loss of less than 1 dB/m in the cladding mode. The robustness of core-cladding mode coupling and recoupling facilitates the exploitation of PCF-LPG for advanced fiber-optic evanescent field sensing and detection.

7677-37, Poster Session

Disturbance detection in distributed fiber optic sensor using time delay estimation

H. Xu, B. Jia, Fudan Univ. (China)

A novel double Sagnac distributed fiber-optic sensor based on Sagnac interferometer for determining the position of disturbance along an optical fiber is presented. The configuration and operating principle of the system is illustrated, the location principle and method for the detection system are analyzed. The system realizes the location of the disturbance using the adaptive time delay estimation with the LMS(least mean square) algorithm in the time domain. Theory analysis and experiment result show that the proposed technology can realize the detection and location of the disturb signal rapidly and effectively, this method is simply and can be obtained easily, and it has high measurement sensitivity and location precision, the largest location error is less than 20 m.

7677-38, Poster Session

Frequency stabilization of a 2.05 μm laser using hollow-core fiber CO_2 frequency reference cell

P. Meras, Jr., I. Y. Poberezhskiy, D. H. Chang, G. D. Spiers, Jet Propulsion Lab. (United States)

We have fabricated a hollow-core CO2-filled fiber frequency reference cell and demonstrated frequency stabilization of a 2.05 μm Tm:Ho:YLF laser using the Pound-Drever-Hall technique. The frequency reference cell is housed in a compact and robust hermetic package that contains a 10 meter long hollow-core photonic bandgap fiber optically coupled to index-guiding fibers. Connectorized fiber pigtails were fusion spliced onto one end and mechanically splice on the other end, the mechanical splice permitting a vacuum valve to evacuate, refill, and adjust the intra-fiber gas pressure. We have demonstrated laser frequency standard deviation decreasing from >450MHz while free-running to <2.4MHz while stabilized.

The 2.05 μm laser wavelength is of particular interest for spectroscopic instruments due to the presence of many atmospheric CO2 and H20 absorption lines in its vicinity. To our knowledge, this is the first reported demonstration of laser frequency stabilization at this wavelength using a hollow-core fiber reference cell. This approach enables all-fiber implementation of the optical portion of laser frequency stabilization system, thus making it dramatically more lightweight, compact, and robust than traditional free-space. It can also provide long interaction lengths without delicate alignment arrangements such as that in Herriott cells. An all fiber arrangement is particularly attractive for use in aircraft and spaceborne coherent lidar instruments.

7677-39, Poster Session

Monitoring the gaps between the platform screen doors and the doors of subway train based on optical time domain reflectrometer

H. Zhang, Z. Wei, P. Wang, L. Fan, L. Guan, Q. Zhao, H. Cui, Stevens Institute of Technology (United States)

Nowadays, subways and light rails often see serious hazards to mankind, such as some passengers were unfortunately restrained and killed at the gaps between the Platform Screen Doors (PSDs) and the doors of the subway train. In this paper, one proposal of real time monitoring system based on optical time domain reflectometer (OTDR) to detect the intrusions at these gaps is presented. In this method the locations and weight of intrusions can be easily obtained by detecting the abrupt power loss of backscattering light caused by the weight of intrusions upon the microbending sensor heads. This method can be easily multiplexed and

extended into a multi-function sensing system, such as to monitor the temperature, smoking and the strains in the tracks, or applied in other fields, such as escalators, board gates for ferries or planes to make these mass transportation systems safe.

7677-40, Poster Session

Improvement of the accuracy of the aircraft center of gravity by employing optical fiber Bragg grating technology

H. Zhang, P. Wang, L. Fan, L. Guan, Q. Zhao, H. Cui, Stevens Institute of Technology (United States)

Safety flight of aircrafts requires that the aircraft center-of-gravity (CG) must fall within specified limits established by the manufacturer. However, the aircraft CG depends on not only the structure of planes, but also the passengers and their luggage. The current method of estimating the weight of passengers and luggage by the average weight may result in a violation of this requirement. To reduce the discrepancy between the actual weight and estimated weight, we propose a method of improving the accuracy of calculating the CG of the plane by weighing the passengers and their personal luggage. This method is realized by a Weigh-In-Motion (WIM) system installed at boarding gates based on optical fiber Bragg grating (FBG) technology. One prototype of WIM is fabricated and tested at lab. The sensitivity of this system is 2 kg and can be further improved by advanced manufacture technology. With the accurate weight of passengers and luggage and the locations of passengers and luggage obtained from boarding cards, the aircraft CG can be calculated correctly. This method can be applied into other fields, such as escalators, boarding gates for ferries.

7677-41, Poster Session

Novel signal demodulation technique to estimate the amount of chirp in fiber Bragg gratings

M. Kondiparthi, Indian Institute of Science (India)

Interrogating chirped fiber Bragg grating (FBG) finds applications not only in dispersion compensation but also in measuring parameters like pressure, force, displacement, strain etc, whose variations can be converted in to a proportional strain/temperature gradient. Predominantly, two methods exist to interrogate chirped FBGs. One based on the measurement of increase in Bandwidth and the other based on increase in spectral area. These methods posses limited chirp resolution. Current proposal deals with a novel approach to interrogate linearly chirped FBGs, which can achieve better chirp resolutions compared to the existing methods.

7677-42, Poster Session

High sensitive static fiber Bragg grating strain sensing using lasers locked to relative frequency reference

M. Kondiparthi, Indian Institute of Science (India)

No abstract available

Conference 7678: Ocean Sensing and Monitoring II

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7678-01, Session 1

Quantification of uncertainties in remotely derived optical properties of coastal and oceanic waters

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Optical properties of oceanic and coastal waters are not only important for describing subsurface light field, but also are useful indexes of environmental status. To meet the demand of IOP products of various users, optical properties of global waters are now generated from operational ocean color satellite sensors (e.g. SeaWiFS, MODIS, MERIS). These products, due to imperfect sensor technology and retrieval algorithms, inherently contain some degrees of uncertainties. Traditionally, an averaged difference (or so-called error) for a data set is usually provided via comparing retrieved values with in situ measurements. This averaged "error" is good at providing an overall picture between the retrieved and measured properties, but cannot indicate uncertainties for a specific product or a pixel, because that uncertainties of ocean color derived products are not spatially uniform. Here, using inherent optical properties (IOP) derived from the Quasi-Analytical Algorithm as an example, we present an approach to quantify pixel-wise uncertainties of the derived total and component contributions. Further, we quantitatively evaluated the uncertainties of the derived IOPs with a simulated dataset, and found that the relative uncertainty is generally within ±10% for total absorption coefficients of oceanic waters, while the uncertainty for pigment or gelbstoff absorption coefficient could be 100% or more. This presentation shows that theoretical basis to evaluate and understand the impacts of the various components on the analytically derived IOPs have been established, and a practical means to quantify the uncertainty of inverted IOPs for each reflectance spectrum is now available. This effort lays the groundwork for generating quality maps of optical properties derived from satellite ocean color images.

7678-02, Session 1

Estimation of the polarized water leaving radiance from above water measurements

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An acquisition system was developed to measure the above water polarized radiance. This system consists of one irradiance sensor for downwelling irradiance, one radiance sensor oriented at 40° zenith angle for sky radiance and three radiance sensors looking down at 40° zenith angle for above water radiance. In order to obtain the polarized radiance a polarizer with orientation of 0°, 90° and 45° respectively were placed in front of the three radiance sensors. The whole system was installed on the bow of the boat for continuous observations of above water polarized radiance along the ship's track during a recent cruise in the NY/NJ Harbor area. Water optical properties were measured by the package towed behind the boat. However, the radiance due to the Fresnel reflection of downward solar irradiance at air-water interface need to be removed from the above water measurement to obtain the polarized radiance which is only due to water since only this part of signal as a result of light and water interaction is closely related to water parameters such as particulate scattering. The surface reflection consists of reflection of sky radiance and reflection of direct solar irradiance. Using a model employing the polarized Fresnel coefficients of the interface the polarized component of reflection will be estimated from the direct measurement of sky radiance and downwelling irradiance data.

7678-03, Session 1

Characterizing bio-optical and ecological features of algal bloom waters for detection and tracking from space

S. A. Ahmed, R. Amin, I. Gladkova, A. Gilerson, M. D. Grossberg, F. Shariar, The City College of New York (United States)

Harmful Algal Blooms (HABs) have been known to occur throughout human history. However, in recent years they have become one of the serious environmental problems in the coastal areas on a global scale, and their detection and tracking is important for protection of public health, and fisheries, including shellfish, and endangered species such as marine mammals. The global nature of the problem has expanded both in its extent and its public perception over last several decades. However, it still remains a challenge to develop effective techniques to predict, detect and track these blooms from space particularly in the optically complex turbid coastal waters. In this study we seek to statistically characterize and recognize bio-optical and ecological features of bloomed and pre-bloom waters and in conjunction with our recently developed low backscattering algal bloom Red Band Difference (RBD) detection approach , advance these techniques and identify and track HABs from space in various coastal regions. Since the RBD technique was developed based on red spectral channels which exist on both Moderate Resolution Imaging Spectroradiometer (MODIS) and Medium Resolution Imaging Spectrometer (MERIS) sensors, we combined data from both of these sensors for identifying and tracking blooms.

7678-04, Session 1

HICO: new capability for coastal hyperspectral imaging from space

R. A. Arnone, U.S. Naval Research Lab. (United States)

No abstract available

7678-05, Session 1

Littoral environmental reconnaissance using tactical imagery from unmanned aircraft systems

K. T. Holland, D. Lalejini, U.S. Naval Research Lab. (United States)

The dynamic nature of very shallow water and surf zone regions requires a reconnaissance approach that can rapidly quantify environmental conditions. Inadequate estimation of these conditions can have substantial impacts on the performance of Naval systems. Given that expeditionary warfare operations can occur over timescales on the order of hours, exploitation of video imagery from tactical vehicles such as Unmanned Aircraft Systems (UAS) has proved to be a reliable and adaptive solution to providing a reconnaissance capability in support of amphibious operations, mine countermeasures, and special warfare. These vehicles can fly at altitudes less than 3000 ft (beneath the cloud cover) to obtain imagery with pixel resolutions better then 1 m. Littoral products that can be created by exploiting UAS imagery include estimates of surf conditions, dominant wave period, wave direction, nearshore currents, and bathymetry. The main advantage of

this approach is that these data are difficult if not impossible to acquire in hostile or denied areas using more traditional in-situ sensing approaches. Also, we leverage the same sensors that are being used operationally at the location for non-environmental purposes.

The technique we have developed works in two phases. The first is to prepare the video stream for advanced analysis by aligning and georegistering individual frames into a mapped movie. The second phase involves processing pixel time series from these movies to determine spatial phase relationships over time. Theoretical models, such as wave dispersion, can then be used to invert for environmental parameters such as the bathymetric surface.

7678-06, Session 1

Using panchromatic imagery in place of multispectral imagery for kelp detection in water

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Multispectral imagery (MSI) taken with high-spatial resolution systems provides a powerful tool for mapping kelp, and has been applied to this process in the Santa Barbara Channel. MSI are not always available, however, and there are systems which provide only panchromatic imagery which would be useful to exploit for the purpose of mapping kelp. Kelp mapping with MSI is generally done by use of the standard Normalized Difference Vegetation Index (NDVI). In broadband panchromatic imagery, the kelp appears brighter than the water because of the strong response of vegetation in the NIR, and can be reliably detected by means of a simple threshold; overall brightness is generally proportional to NDVI. Confusion is caused by other bright pixels in the image, including sunglint. This research seeks to find ways of mitigating the number of false alarms using spatial image processing techniques. Methods developed in this research can be applied to other water target detection tasks.

7678-07, Session 1

Comparison of primary productivity models in the Southern Ocean: preliminary results

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Concerns on addressing eco-responses to climate change advocate improvement on models to estimate ocean primary productivity (PP) based on satellite observations. A very recent study (Friedrichs et al., 2009), which included comparisons of PP estimates obtained from 21 different models to a tropical Pacific PP database, shows that almost all models underestimate the observed variance of PP. Uncertainties in the input variables might account for the differences between model estimates and sea truth data to a great extent. And all the models failed to capture a shift from low biomass-normalized productivity in the 1980s to higher biomass-normalized productivity in the 1990s, which was revealed by the in situ dataset. Models involved in this comparative study all used chlorophyll concentration (Chl) in the surface water as a primary input variable. None of them used phytoplankton absorption as an input variable. Earlier and recent studies suggest that phytoplankton absorption is a strong predictor of primary productivity in the surface ocean, and this variable can be analytically derived from satellite ocean color with less uncertainty than Chl. It is thus important to characterize the difference of phytoplankton absorption-based models from that of biomass-based models. To this objective, we here present PP in the Southern Ocean based on both phytoplankton absorption and phytoplankton biomass, and discuss their advantages and disadvantages.

7678-08, Session 1

Validation of the three-band chlorophyll-a model in turbid water: a case of Taihu Lake, China

Y. Wei, Nanjing Normal Univ. (China)

In this paper, the routine monitoring sampling data of Taihu Lake from June to September in 2004 was used to validate the three-band chlorophyll-a inversion model(TBCM) proposed by Gitelson. The range of chlorophyll-a concentration(ChlaC) in the lake is from 5 to 374ug/L and the average is 49ug/L. Water surface spectrum were measured by ASD FieldPro. The result shows, (1) TBCM can not used directly in the Taihu Lake. (2) TBCM built by single month data has lower error, its RMSE changed between 8.0-17.6ug/L; The model from all data has higher error, and RMSE is 26.8ug/L. (3) When data collected in August and September is used to validate the model built by data in June and July, RMSE increased from 17.2ug/L (in model) to 50.7ug/L. (4)Samples with higher or lower ChlaC has higher error. When samples collected at alga bloom (ChlaC>120ug/L in general) and samples with lower ChlaC (<20ug/L) were not used, RMSE of model built by June and July data is 6.2ug/L, and RMSE of estimated Chla in August and September will be 17.0ug/L. This paper points out that TBCM can be used to estimate Chla with higher precise in Taihu Lake, but model parameter must be refined according to the area and the season before it is used in practical work.

7678-10, Session 2

Patch recognition of algal blooms

K. H. Szekielda, The City Univ. of New York (United States); J. Bowles, D. B. Gillis, W. Snyder, U.S. Naval Research Lab. (United States); W. D. Miller, Computational Physics Inc. (United States)

Derivative analysis of radiance spectra in the region from 0.4 to 0.8 μm for oligotrophic water and near coastal water show similar location of absorption bands but with different amplitudes. For this reason, radiance spectra were also analyzed without atmospheric correction, and various approaches to interpret radiance data over plankton blooms were investigated.

The impact of Fraunhofer lines and atmospheric absorption bands interfere with the spectral location of absorption bands of photosynthetic pigments in plankton. Hyperspectral data were used to address this interference on identifying absorption bands by applying derivative analysis of the spectra.

Algal blooms show elevated radiance data even at longer wavelengths compared to oligotrophic water and may show radiance values of around 800 W/m2/micrometer/sr at 0.8 μm. Therefore, the use of a spectral range beyond 0.55 μm is useful to describe bloom characteristics. In particular, the slope between 0.55 to 0.80 μm shows an advantage to depict gradients in plankton blooms. Cluster analysis and ratio techniques were found to assist in the separation of ocean color gradients and distinguish bio-geochemical provinces.

Using the slope of spectra from plankton blooms, in connection with scatter diagrams at various wavelengths, shows that details can be revealed that could not be recognized in single channels.

7678-11, Session 2

Forecasting of aerosol extinction of the sea and coastal atmosphere surface layer

G. A. Kaloshin, Institute of Atmospheric Optics (Russian Federation)

The focus of our study is the extinction and optical effects due to aerosol in a specific coastal region.

The aerosol microphysical model of the marine and coastal atmosphere surface layer is considered. The model is made on the basis of the long-term experimental data received at researches of aerosol sizes distribution function (dN/dr) in the band particles sizes in 0.01 - 100 µk. The model is developed by present time for the band of heights is 0 - 25 m. Bands of wind speed is 3 - 18 m/s, sizes fetch is up to 120 km, RH = 40 - 98 %.

Key feature of model is parameterization of amplitude and width of the modes as functions of fetch and wind speed. In the paper the dN/dr behavior depending at change meteorological parameters, heights above sea level and fetch (X) is show.

On the basis of the developed model with usage of Mie theory for spheres the description of last version of developed code MaexPro (Marine Aerosol Extinction Profiles) for spectral profiles calculation of aerosol extinction coefficients ( ) in the wavelength band, equal = 0.2 - 12 µm is presented. The received results are compared with models NAN and ANAM.

Also ( ) profiles for various wind modes (combinations X and U) calculated by MaexPro code are given. The calculated spectrums of ( ) profiles are compared with experimental data of ( ) received by a transmission method in various geographical areas.

7678-12, Session 2

Multi-frequency and polarimetric measurements of perturbed water surface microwave reflective and emissive characteristics by C- and Ku-band combined scatterometer-radiometer systems

A. K. Arakelyan II, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia)

In this paper the results of simultaneous and spatially coincident, multi-frequency, polarimetric, spatio-temporally collocated measurements of waved pool water surface microwave reflective (radar backscattering coefficient) and emissive (brightness temperature) characteristics angular dependences at 5.6GHz and 15GHz will be represented. Angular measurements were carried out for various water surface roughness parameters at clear air (atmosphere) condition. For the measurements C and Ku-band, polarimetric, combined scatterometer-radiometer systems were used, set jointly on a mobile buggy moving along the measuring platform. Structures, operational features and main technical characteristics of the utilized systems will be represented in this paper too.

The measurements were carried out from a stationary, quarter-circle shaped measuring platform of 6.5m of radius. The platform allows research angular dependences of microwave reflective and emissive characteristics of the same area of the observed surface. The measurements were curried out under various temperature, roughness parameters, weather and observation conditions. Unique results have been obtained on water surface reflectance and emittance at an appearance of heavy clouds and at the heavy rain (cat and dog) under the angle of incidence 30 degree.

The methodology of experiments' performance and field calibration of the measuring system and the measured results will be discussed. Frequency, polarization and angular relationships between waved water surface radar backscattering coefficients, brightness temperatures and the observed surfaces parameters will be built, for various water and air temperatures, surface wave and wind parameters. As well as correlative properties between waved water surface radar backscattering coefficients and brightness temperatures due to the change of water surface wave and wind parameters, water and air temperatures will be represented.

7678-13, Session 2

Clouds and rain effects on perturbed water surface microwave reflection and emission at 37GHz

M. Grigoryan, A. K. Arakelyan II, ECOSERV Remote Observation Ctr. Co. Ltd. (Armenia)

In this paper the results of simultaneous and spatially coincident measurements of waved pool water surface microwave reflective (radar backscattering coefficient) and emissive (brightness temperature) characteristics angular dependences at 37GHz will be represented. Angular measurements were carried out for various water surface roughness parameters at clear air (atmosphere) condition. As well as unique results of measurement of water surface reflectance and emittance at an appearance of heavy clouds and rain at the angle of incidence 300. For the measurements a Ka-band, combined scatterometer-radiometer system were used. The structure and operational features of the utilized system will be discussed in the paper too. The main characteristics of the microwave sensor are:

Central frequency - 37GHz;

Radar pulse duration - 25ns

Radar pulse power - 30mW

Radar receiver's bandwidth - ~40MHz;

Radiometer receivers bandwidth - ~1GHz;

Horn antenna with a beamwidth - 70;

Radar receivers noise factor - ~2dB;

Radiometer receiver's noise factor - ~300K;

Radar channel's sensitivity at 1s- ~0.1dB;

Radiometer Channel's sensitivity at 1s- ~0.3K.

The principal peculiarities of the utilized device are its originality in spatio-temporally combining of functionality of microwave active-passive channels of observation under the condition of short range sensing application of the system. The minimum operational range for the system's scatterometer is 5m, at a far zone condition of sensing.

The measurements were carried out from a stationary, quarter-circle shaped measuring platform of 6.5m of radius. The platform allows research angular dependences of microwave reflective and emissive characteristics of the same area of the observed surface. The measurements are curried out under various conditions of perturbation of the surface, and air and water temperatures .

The methodology of experiments' performance and field calibration of the measuring system and the measured results will be discussed.

7678-14, Session 2

Ocean observation from NOAA National Data Buoy Center's platforms

C. Teng, National Oceanic and Atmospheric Administration (United States)

U.S. National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) has three major real-time ocean observing networks: (1) Weather and Ocean Platform (WxOP) Network, (2) Tropical Atmosphere/Ocean (TAO) Buoy Network, and (3) Tsunameter Buoy Network.

The WxOP Platform network includes 114 moored buoys and 51 land-based Coastal-Marine Automated Network (C-MAN) stations. NDBC's moored buoys are deployed in the coastal and offshore waters from the Western Atlantic to the Pacific Ocean around Hawaii, and from the Bering Sea to the South Pacific. C-MAN stations are usually located near the U.S. coastal water. In addition to being used in operational forecasting, warnings, and atmospheric models, data from moored buoy and C-MAN stations are used for scientific and research programs, emergency response to chemical spills, legal proceedings, and engineering design.

The TAO buoy network, designed for the study of year-to-year climate variations related to El Nino and the Southern Oscillation (ENSO), consists of 55 moored ocean buoys along the equatorial Pacific Ocean region extending from 9N Latitude to 8S Latitude and 95W Longitude to 165E Longitude. The Tsunameter Buoy Network consists of 39 tsunameter buoy systems in the Pacific Ocean, Gulf of Mexico, and Atlantic Ocean at sites in regions with a history of generating destructive tsunamis to ensure early detection to tsunamis and to acquire data critical to real-time forecasts.

In this paper, NDBC's 250+ ocean observing platforms and systems will be described. Some interesting and significant data collected by these platforms and systems will be presented.

7678-15, Session 2

Glider optical measurements and proposed BUFR format for data QC and storage

W. Hou, M. Carnes, R. A. Arnone, A. D. Weidemann, U.S. Naval Research Lab. (United States); D. Bryant, Naval Oceanographic Office (United States)

Unmanned underwater vehicles are becoming an increasingly important platform in oceanographic research, where continuous in-situ sampling throughout the water column is critical to understanding the ocean circulation and related biological, chemical and optical activity. The latter directly affects field operations and remote sensing capabilities from space. A unified approach is necessary for data quality control (QC), access, and storage considering the vast amount of data from continuously deployed gliders across large areas and long durations. The Binary Universal Form for the Representation of meteorological data (BUFR) is adapted to include physical and optical parameters from various sensor suites onboard underwater vehicles. The provisional BUFR template and related BUFR descriptors and table entries have been developed by the U.S. Navy for ocean glider profile data and QC results. Software written in FORTRAN using the ECMWF BUFRDC software library has been implemented to perform both the encoding and decoding of BUFR files from and to Network Common Data Form (NetCDF) files. This presentation will also discuss data collected from sensors onboard deep water seagliders and shallow water slocum gliders from the field, including issues specific to optical sensors at various depths.

7678-16, Session 2

Airborne multispectral detecting system for marine mammals survey

Y. Podobna, J. Schoonmaker, J. Sofianos, D. Medeiros, C. D. Boucher, D. Oakley, S. Saggese, Advanced Coherent Technologies LLC (United States)

This work presents an electro-optical multispectral capability that detects and monitors marine mammals. It is a continuance of Whale Search Radar SBIR program funded by PMA-264 through NAVAIR. The low-weight, multi-spectral, turreted imaging system is designed for airborne and ship based platforms to detect and monitor marine mammals. The system tests were conducted over a whale breeding and feeding area in Hawaii. The results of the tests and the unique system description are presented. Developing an automatic whale detection algorithm and building a distance sampling survey are discussed and demonstrated.

7678-18, Session 2

Determination of environmental pollution source of Oman Sea continental shelf in the base of sedimentary studies

A. Mohammadi, Geological Survey of Iran (Iran, Islamic Republic of)

The study area is a part of continental shelf of Oman sea (Tahroui area) that is located in the south of Iran. 78 surficial sediments in the systematic network 5*5 kilometers form continental shelf, 23 sediments sample from tidal flat and shore line and 1 meter core from sea bed sediments were taken. The sediments were analyzed by ICP and Granolometry. 9 type of sediments exist in this area. The distribution map of elements show that maximum value of As,Cd,Pb,Cr,Co,Cu,Zn and Ni concentrate at the lagoon (khour). Correlation coefition between (Cd,Pb,Cr,Co,Cu,Zn,Ni) and concentrations of Calcium is negative but Correlation coefition between As and Calcium is positive. But Correlation caefition between (Cd,Pb,Cr,Co,Cu,Zn,Ni) and Al2O3,Fe2O3,Ti and Mn is positive. the result show the origin source of these elements are detrical. The value of these elements in the surficial sediments and 1 meter core down to seabed relative is the same. Maximum consentration of this element in the coastal zone and tidal channels, correlation coefition between these elements. The same value of these elements in the recent sediments and subsurface show that the source of these elements is geogenic and is related to geological characteristic in the upland.

7678-19, Session 3

Efficient laser pulse time dispersion codes for turbid undersea imaging and communications applications

F. R. Dalgleish, F. M. Caimi, A. K. Vuorenkoski, B. Ramos, W. B. Britton, Florida Atlantic Univ. (United States); T. E. Giddings, J. J. Shirron, Metron, Inc. (United States); C. H. Mazel, Physical Sciences Inc. (United States)

No abstract available

7678-20, Session 3

Assessment of underwater scattering polarization and visibility

J. Zhou, A. Tonizzo, I. Ioannous, A. Gilerson, B. M. Gross, F. Moshary, S. A. Ahmed, The City College of New York (United States)

In this paper we examine the impact of measured underwater polarization characteristics on visibility. Underwater characteristics were measured both in the principal plane and outside the principal plane, with data collected during several cruises in the Chessapeake/Virginia and New York Harbor/Hudson river areas using a multi-angular hyperspectral sensor system. This system, recently developed by us, consists of three hyperspectral Satlantic radiance sensors, each with a polarizer positioned in front of it, and with polarization axes aligned at 0, 90 and 45 deg. Measurements are made with scattering angles from 0-180 degrees with respect to the solar illumination. At the same time as the hyperspectral measurements are made, the inherent optical properties such as absorption and attenuation were also recorded. The waters studied varied from clear open ocean water with attenuation at 550nm c (550) less than 0.25m-1 to turbid coastal waters with c(550) of more than 4m-1. In order to examine how polarization techniques can help to improve underwater visibility in these field conditions, we computed the related point spread and modulation transfer function from the polarized field measurements, and included the examination of the impact of scattered polarized veiling light inherent in the field data.

Various geometric viewing orientations are then explored to examine how the polarization of the background light in and out of the principal plane affects underwater visibility.

7678-21, Session 3

The impact of algal fluorescence on the underwater polarized light field

A. Tonizzo, J. Zhou, A. Gilerson, B. M. Gross, F. Moshary, S. A. Ahmed, The City College of New York (United States)

Previous work by us has made use of the unpolarized nature of algal fluorescence and the partially polarized properties of elastic scattering (including particulate) in sea water to separate, using polarization sensitive detectors below the surface, the fluorescence signal from the total upwelling radiance. Our newly developed underwater sensor system, capable of measuring multi-angle hyperspectral polarized light fields in-situ, opens the possibility of studying the efficacy of the polarized discrimination techniques on the basis of comprehensive in-situ measurements. Analysis of underwater polarization characteristic recently measured by us have confirmed that fluorescence, because of its unpolarized nature, markedly impacts (reduces) the degree of polarization measured in the fluorescence spectral region. The polarized data were collected in several cruise campaigns in the Chessapeake/Virginia area and New York Harbor/Hudson river areas. The examined water varied from clear oligotrophic water with chlorophyll concentration less than 1mg/m3 to turbid eutropic water with chlorophyll concentration more than 20 mg/m3. The relationships between the change in polarization and the fluorescence contribution is examined, and its efficacy for underwater fluorescence retrieval evaluated for various water conditions, and scattering geometries evaluated and its range of applicability defined.

7678-22, Session 3

Effects of temperature and salinity on light scattering by seawater

X. Zhang, L. Hu, Univ. of North Dakota (United States)

A theoretical model on light scattering by water was developed from the thermodynamic principles and was used to evaluate the effects of temperature and salinity. The results agreed with the measurements by Morel within 1%. The scattering increases with salinity in a non-linear manner and the typically-assumed linear variation would underestimate and overestimate scattering at lower and higher concentrations, respectively. The spectra shape, which is normally assumed following power-law function, varies only slightly with salinity. Resembling the density-temperature relationship of water, there seems exists a temperature at which the minimum scattering occurs and this temperature increases with salinity. Unlike the Inherent Optical Properties (IOP's), the scattering of seawater as a mixture is less than the sum of scattering by individual salt solutions.

7678-23, Session 3

Experimental tests of femtosecond pulse laser propagation in turbid water: a beautiful hypothesis shot down

M. J. DeWeert, BAE Systems (United States)

No abstract available

7678-24, Session 4

Image feature detection and matching in underwater conditions

K. D. Oliver, Univ. of South Carolina (United States); W. Hou, U.S. Naval Research Lab. (United States); S. Wang, Univ. of South Carolina (United States)

The main challenge in underwater imaging and image analysis is to overcome the effects of blurring due to the strong scattering of light by the water. This blurring adds difficulty to already challenging problems like object detection and localization. The current state-of-the-art approaches for object detection and localization normally involve two components: (a) a feature detector that extracts a set of feature points from an image, and (b) a feature matching algorithm that tries to match the feature points detected from a target image to a set of template features corresponding to the object of interest. A successful feature matching indicates that the target image also contains the object of interest and vice versa. For underwater images, the target image is taken in underwater conditions while the template features are usually extracted from one or more training images that are taken out of water or in different underwater conditions. In addition, the objects in the target image and the training images may show different poses, including the rotation, scaling, translation transformations, and the change of perspectives. In this paper we investigate the effects of various underwater point spread functions on the detection of image features, using many widely used feature detectors, and how this affects the capability of these features when they are used for matching and object detection. This research provides insights to further develop robust feature detectors and matching algorithms that are suitable for detecting and localizing objects from underwater images.

7678-25, Session 4

Interest of correlation-based automatic target recognition in underwater optical images: theoretical justification and first results

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To identify and position underwater man-made objects (e.g. mines), optical cameras are often used along sonar [1]. Doing this automatically in real time is hard: automatic target recognition is a challenging task, and poor lighting conditions under water make it even harder [2].

In this paper, we explore the use of optical correlation--based recognition [3]. Correlation can be defined as a comparison between two images (e.g. a target image and a reference image) and can be achieve extremely fast. However, to perform a good correlation decision, object recognition requires the comparison of an input image with a huge database of references [4]. To overcome this limitation, we propose to use composite filter techniques, which drastically reduce the number of needed comparisons to identify target images [5]. These are recent techniques that were not enough exploited in the underwater context. In addition, they allow the integration of preprocessing directly in the correlation filter manufacturing step to enhance visibility of objects (for example) while reducing processing time.

We want to obtain filters that are independent from all noises and contrast problems found in underwater videos. To create filters, correlation techniques permit the use of computer-generated images instead of underwater optical images. Moreover, 3D computer-generated images provide images of objects with all desired scales and angle shots.

Our paper is organized as follows. First, we present the setting, the studied targets and the context of underwater optical imaging. Then we discuss our choice of using optical correlation-based methods to recognize underwater objects, as compared to the state of the art. We explain our filter manufacturing, our decision of trying the use of computer-generated images instead of underwater images and the

integrated preprocessing features to improve target images without increasing processing time. Finally we present first results obtained with data acquired at sea that seem to validate our approach.

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7678-26, Session 4

Incremental knowledge assimilation system (IKAS) for mine detection

J. Porway, H. Nguyen, J. Yadegar, C. Raju, K. M. Varadarajan, UtopiaCompression Corp. (United States)

Current mine detection algorithms are often unreliable in varying environmental conditions due to distracters in the sea floor textures that can cause false positives. In these varying conditions, mine detection algorithms will significantly benefit from incorporating in-situ information and context. To address this need, we present an adaptive incremental learning system that incorporates in-situ information at both detection and classification steps. The first stage of processing employs a two-pronged approach for detection: 1) using filter responses over the image, a Background Adaptive ANomaly detector (BAAN) identifies statistically likely target regions. Using this information, BAAN classifies the background type and updates its detection using background-specific parameters, 2) Optimal-tradeoff filters, built from examples of mines and the power spectral density of background images, are employed to specifically identify certain known targets. The combination of these two techniques produces regions of the image that are likely to contain targets. Novel Adaptive Bagging Based Decision Forest (ABAFOR) and Fully Adaptive Nearest Neighbor (FAAN) classifiers are then used to classify mine regions from false alarms. These classifiers perpetually assimilate new and relevant information into their existing knowledge database in an incremental fashion, allowing improved classification accuracy and capturing concept drift in the target and background classes. Experiments show that IKAS can detect underwater mines in datasets provided by the Office of Naval Research at >90% classification accuracy and better than real-time speed tasks performed. We have also demonstrated that the system can incrementally improve its detection accuracy by constantly learning from new samples.

7678-27, Session 4

Optical characterization of a ventilated cavity

J. T. Borck, T. Kane, The Pennsylvania State Univ. (United States); L. T. Antonelli, Naval Undersea Warfare Ctr. (United States)

The optical characteristics of an air/water interface have been widely studied for natural interface formations. However, the creation and management of artificial cavities creates a complicated interaction of gas and liquid that makes optical sensing and communication through the interface challenging. A ventilated cavity can reduce friction in underwater vehicles, but the resulting bubble drastically impedes optical and acoustic propagation. The complicated interaction at the air-water boundary yields surface waves and turbulence that make the optical properties difficult to model and compensate for.

Our experimental approach uses a narrow laser beam to probe the surface of the interface and measure the beam deflection and lensing effects. Using a vehicle model with a cavitator in a water tunnel, a laser beam is propagated through the boundary and projected onto a target grid. The beam projection is captured using a high-speed camera, allowing us to measure and analyze beam shape and deflection. This approach has enabled us to quantify the temporal and spatial periodic variations in the cavity boundary. This information has allowed us to characterize the cavity surface and determine the scale, shape, roughness, and periodicity of its features.

7678-28, Session 4

Sonar authentication performance evaluation in realistically simulated undersea channels

B. G. Mobasseri, Villanova Univ. (United States); R. S. Lynch, Naval Undersea Warfare Ctr. (United States)

Sonar is the key technology in undersea sensing. In large scale naval operations it is helpful to distinguish friendly sonar from other acoustic emissions that may exist as part of the natural undersea environment, or from pings that may have originated from hostile forces, or, from bogus echoes fabricated by the enemy. Marking sonar by identifying signatures, makes possible to identify or counter fraudulent transmissions. These objectives can be met if sonar pulses are embedded with identifying signatures, not in subbands but as intrinsic fabric of the signal. In previous work we have introduced digital watermarking to the problem of sonar authentication. In this work we have developed performance bounds using authentic undersea propagation conditions as modeled by the University of Washington Sonar Simulation Toolset(SST). Watermark is first embedded with a signature derived from a PN code using a secure ket only available to authorized ships. Embedding follows a spread spectrum model where the sonar pulse is windowed in time and block transformed using DCT. Then selected DCT coefficients are additively modified by the secure watermark. The detector is a maximum likelihood detector where the sufficient statistics is integrated over hundreds of blocks in a single sonar ping. This integration provides the robustness needed in challenging undersea environments. The channel model in SST is shallow water(200m deep) with transmitter/receiver situated 2000m apart at a depth of 10m. The propagation loss alone for this channel is 67dB. ROC curves were obtained for two types of channels, 1) straight-line path with spherical spreading and exponential absorption, 2) multipaths with two surface and two bottom bounces, all in the presence of additive Gaussian noise. The ROC curves consists of false alarm rates(watermark detected when none is present) and miss probabilities(watermark present and detected). We have established that the highest detectable SWR(above 90% correct detection rate and less than 10% false alarm) using a single ping requires an SWR(signal to watermark ratio) of 30dB. If additional pings can be processed detection and false alarm rates can be improved to 99% and 1% respectively . Robustness to random noise is achieved by the fact that noise and the watermark sequences are uncorrelated. In a straight path channel SNR as low as 0dB can be mitigated.

7678-29, Session 5

Biosensor UUV payload for underwater detection

A. W. Kusterbeck, P. Charles, S. Trammell, B. Melde, A. Adams, J. Deschamps, U.S. Naval Research Lab. (United States)

Increased emphasis on maritime domain awareness and port security has led to the development of unmanned underwater vehicles (UUVs) capable of extended missions. These systems rely most frequently on well-developed side scan sonar and acoustic methods to locate potential targets. The Naval Research Laboratory (NRL) is developing biosensors for underwater explosives detection that complement acoustic sensors and can be used as UUV payloads to monitor areas for port and harbor security or in detection of underwater IEDs/UXO and other biochemical

threats. The prototype sensor has recently been demonstrated to detect TNT and RDX in seawater at trace levels when run in a continuous sampling mode. To overcome ongoing issues with sample preparation and facilitate rapid detection at trace levels in a marine environment, we have been developing new mesoporous materials for in-line preconcentration of explosives and other small molecules, engineering microfluidic components to improve the signal, and testing alternative signal transduction methods. Additional work is being done to optimize the optical components and sensor response time. We will describe the results of these current studies and our ongoing efforts to integrate the biosensor with existing detection technologies to reduce false positives. In addition, we will present the results of recent field tests that demonstrate the prototype biosensor performance as a UUV payload.

7678-30, Session 5

Electroactive material-based bend sensors

R. B. LaComb, J. A. LaComb, Naval Undersea Warfare Ctr. (United States)

The capability to accurately estimate the strain and orientation of cables in an undersea environment is important for a multitude of applications. A novel sensor is presented that implements conformal electroactive materials to act as a bend sensor. Electro-active materials (EAM) are known for their actuator functionality but certain EAMs are capable of sensing as well. New advances in materials such as Ionic Polymer Metal Composites (IPMC) are proving suitable for quasi-static sensor applications. These sensors are low power, conformal and produce directionally dependent output voltages which are linearly proportional to deflection, with voltage polarity representative of the deflection direction. IMPCs are capable of being morphed for increased sensitivity.

7678-31, Session 5

Combined pre-concentration and real-time in-situ chemical detection of explosives in the marine environment

M. Dock, R. J. Harper, E. Knobbe, ICx Nomadics, Inc. (United States)

ICx Nomadics has developed the first known real-time sensor system that is capable of detecting chemical signatures emanating from underwater explosives, based upon the same amplifying fluorescent polymer (AFP) fluorescence-quenching transduction mechanism that the Fido® family of explosives detectors utilize. The SeaPup is capable of real-time detection of the trace chemical signatures emanating from submerged explosive compounds and has been successfully tested on various marine platforms, including a crawler robot, an autonomous underwater vehicle (AUV), and a remotely operated underwater vehicle (ROV).

The present work is focused on advances in underwater in-situ chemical sensing; wherein trace amounts of dissolved explosive compounds may be detected and discriminated from other chemical species found in the marine environment. Recent progress with the SeaPup platform have focused on increasing the sensitivity of the AFP matrix through the development of a preconcentration system designed to harvest explosive analytes from a larger sample volume over a predetermined period of time. This permits real time monitoring of chemical plumes during the approach to a potential source, combined with the lowered limit of detection from extended sampling of targeted items.

SeaPup has been shown to effectively map "explosive scent plumes" emanating from an underwater source of TNT, and the preconcentration system has previously been demonstrated to enhance sensitivity be over 2 orders of magnitude in a time window of minutes.

7678-33, Session 5

Simulations for a wide-swath synthetic aperture microwave radiometric imaging of wind speed and rain rate in hurricanes

R. Amarin, S. El-Nimri, S. Alsweiss, W. L. Jones, J. Johnson, Univ. of Central Florida (United States)

Airborne remote sensing of environmental parameters in tropical storms and hurricanes is important for real-time operational forecasting of hurricane intensity and warnings at the NOAA National Hurricane Center. One of the major operational remote sensors is the Stepped Frequency Microwave Radiometer, SFMR, which is a nadir viewing, multifrequency C-band aircraft instrument routinely flown by NOAA and the USAF reconnaissance aircraft to measure surface wind speed and rain rate. This paper describes a computer simulation developed by the Central Florida Remote Sensing Laboratory (CFRSL) in support of the development of the next generation airborne microwave radiometer, which will extend the SFMR measurements to make a wide swath image of the storm. This Hurricane Imaging Radiometer, HIRAD, is currently being developed by NASA's Marshall Space Flight Center, in collaboration with the NOAA Hurricane Research Division, the University of Michigan and the University of Central Florida.

The CFRSL has developed a comprehensive computer simulation using MATLAB that calculates the instrument radiance measurements during a simulated aircraft overflight of a hurricane. This model is driven by a realistic, 3 dimensional hurricane atmosphere and surface wind field "nature run" provided by a numerical hurricane model. To these theoretical radiances, we add instrumental errors in a realistic Monte Carlo simulation, and estimate the surface wind speed and rain rate using a maximum likelihood estimation retrieval algorithm. Through multiple simulated observations and retrievals, we provide a statistical estimate of the geophysical measurement errors over the expected range of wind speeds, rain rates and measurement swath location.

7678-34, Poster Session

TPDSci.com: a continually updated monograph of selected topics in the optics of turbid media

M. Jonasz, MJC Optical Technology (Canada); W. Hou, U.S. Naval Research Lab. (United States)

Research in the optics of turbid media progresses by combining expertise from many diverse fields of particle and dispersion science. In particular, such research relies on the knowledge of physical properties of particles and particle dispersions, particle and dispersion optics, as well as optical imaging and image processing. A substantial rate of increase in the number of publications in each of these fields, as well as the increasingly busy researchers' schedules, will make it more and more difficult to systematically and comprehensively follow developments in these fields.

A unique collaborative on-line monograph: "Topics in Particle and Dispersion Science" (www.tpdsci.com) aims at helping researchers to follow these developments by providing a continually updated perspective on key results in a wide range of fields relevant to the optics of turbid media, such as natural waters. Based on a systematic review of well over 1000 papers per month, published in nearly 100 journals, TPDSci combines (1) an expert-based survey of relevant publications, continuously built from few sentences-long conclusion-oriented summaries, with (2) textbook-format extended notes on key issues, and (3) a growing and frequently verified contact list of researchers that are active in these fields.

Conference 7679: Micro- and Nanotechnology Sensors, Systems, and Applications II

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Micro- and Nanotechnology Sensors, Systems, and Applications II

7679-01, Session 1

Engineered carbon nanotube and graphene for nano-electronics

E. Yang, Stevens Institute of Technology (United States)

The outstanding electrical properties of both carbon nanotubes (CNTs) and graphene make them exceptional candidate materials for the development of advanced nanoelectronic devices. However, despite the promise of vastly superior performance of these materials, several fundamental issues in the fabrication and characterization need to be researched and resolved to realize their full potential. In this regard we are investigating nanodevices based on CNT and graphene nanostructures aimed at developing nanoelectronic devices, nanoactuator systems and nanosensors for cross-disciplinary applications. Overcoming the technical challenges of working with these materials will enable one to leverage their outstanding electrical properties in the development of next-generation devices with unrivaled functionality for use in applications such as sensors, detectors, system-on-a-chip, system-in-a-package, programmable logic controls, energy storage systems and future electronic systems.

7679-02, Session 1

New optical detector concepts for space applications

D. A. Cardimona, D. Huang, Air Force Research Lab. (United States)

Detecting objects in space from space poses some very stringent conditions. The objects are usually very distant, and therefore very dim and possibly only imaging to a single pixel. The background is extremely low (perhaps around 10^9 photons/cm^2/s). The objects range from hot to cold and the environment is a vacuum filled with ionizing radiation. These conditions certainly stress the material systems used and the sensitivities required. Always keeping these conditions in mind, we have been performing research in surface plasmon polariton (SPP) interactions for near-field enhancement of incoming signals for use as an optical signal amplification scheme for quantum detectors. We have also investigated quantum interference and classical interference when a three-level system interacts with both a cavity field mode and an external driving field mode. We found that under certain circumstances the cavity field evolves to be equal in magnitude to, but 180° out-of-phase with the external pump field when the pump field frequency equals the cavity frequency. At this point, the resonance fluorescence from the atom in the cavity goes to zero. This is quite different from the quantum interference that occurs under the right circumstances, when the state populations are coherently driven into a linear combination that is decoupled from any applied field - and population is trapped in the excited states, thus allowing for a population inversion and an amplification of incoming optical signals. Finally, we discuss our lateral-biasing scheme for tunable detection across the infrared using quantum dots in quantum wells.

7679-03, Session 1

Nanocrystalline ZnO microwave thin film transistors

B. Bayraktaroglu, K. D. Leedy, R. Neidhard, Air Force Research Lab. (United States)

Nanocrystalline ZnO (nc-ZnO) thin films composed of 20-50nm crystals of ZnO can be deposited on a variety of surfaces. They can be used as transparent conductors when doped with Al or Ga, or as the active layer of thin film transistors (TFT) when not doped. In this study, nc-ZnO films suitable for TFT applications were deposited in a Pulsed Laser Deposition (PLD) system optimized for uniform films over large area (4-inch wafers). TEM images of nc-ZnO films deposited on SiO2 gate insulators showed that they are made of closely packed nanorods showing strong orientation. Nc-ZnO TFTs exhibited record figure-of-merit device numbers that are comparable to single crystal Si transistors. These include on/off ratio of 10^{12}, current density of >400mA/mm and field effect mobility of 110 cm2/V.s. The device stability was examined by storing devices under constant gate and drain bias conditions up to 24 hr at room temperature and then re-measuring the transfer characteristics. No shift in threshold voltage was observed within experimental limitations. High speed operation of nc-ZnO TFTs was demonstrated by fabricating short gate length (Lg=1.2um) devices on Si substrates. We have achieved fT and fmax values of 3GHz and 10GHz, respectively. To our knowledge, these are the highest cut-off frequency values achieved with thin film transistors and illustrate the potential of ZnO thin film transistors for high frequency applications. Even higher frequency operation is expected as the gate length is further reduced.

7679-04, Session 1

Photodetectors on structures with vertically correlated quantum-dot clusters

V. Mitin, A. V. Sergeev, L. Chien, A. Antipov, G. Strasser, Univ. at Buffalo (United States)

Long photocarrier lifetime is a key issue for improving of room-temperature infrared photodetectors. Detectors based on quantum dot structures have the strong potential to overcome the limitations in quantum well detectors due to various possibilities for engineering of specific properties. Here we review photocarrier kinetics in traditional QDIPs and present results of our investigations related to the QD structures with vertically correlated dot clusters (VCDC). Modern technologies allow for fabrication of various VCDC with controllable parameters, such as the cluster size, a distance between clusters, dot occupation etc. Modeling of photocarrier kinetics in VCDC structures shows that the photocarrier capture time exponentially increases with increasing of the number of dots in a cluster. It also exponentially increases as the occupation of a dot increases. At the same time, the capture processes are weakly sensitive to geometrical parameters, such as the cluster size and the distance between clusters. Compared with ordinary quantum-dot structures, where the photoelectron lifetime at room temperatures is of the order of 1-10 ps, the VCDC structures allow for increasing the lifetime up to three orders of magnitude. We also study the nonlinear effects of the electric field and optimize operating regimes of photodetectors. We found that most of the nonlinear effects can be understood in the model of electron heating. For example, this model adequately describes nonmonotonic dependence of the photoconductive gain as a function of the electric field. Complex investigations of these structures pave the way for optimal design of the room-temperature QDIPs.

7679-05, Session 1

High-operating temperature (HOT) dual-band SWIR (900nm-1700nm) and LWIR (7.5µm-10µm) quantum dot infrared photodetector

J. N. Vaillancourt, Applied NanoFemto Technologies (United States); X. Lu, Univ. of Massachusetts Lowell (United States)

A preliminary SWIR (900nm-1700nm) and LWIR (7.5um-10um) dual-

band QDIP in a standard TO-66 package. Photodetectivities of 4x108 cmHz1/2/W and 1.4x107 cmHz1/2/W have been achieved at 270K for the SWIR and the LWIR bands, respectively. High photoresponsivities of 1.6A/W and 0.025A/W have also been demonstrated at 270K for the SWIR and the LWIR bands, respectively. These results not only demonstrated the feasibility of achieving miniature multispectral photodetectors with TE-cooled and ultra-low power consumption, but also showed the promising potentials of the QDIP technology in ultra-compact multispectral imaging systems for portable, handhold and small and micro unmanned air vehicles (UAVs) applications.

7679-06, Session 1

Multimodal sensing with nanoscale quantum dots and type-II superlattices

S. Krishna, The Univ. of New Mexico (United States)

As the third generation of infrared imaging systems are being developed there is an increased emphasis on multicolor sensing. This presentation will be focused on the design, growth and fabrication of infrared detectors for multimodal sensing using two material systems, which are emerging as promising technologies for mid infrared sensors. These are (i) InAs/InGaAs self assembled quantum dots in well (DWELL) Detectors and InAs/(In,Ga)Sb strain layer superlattices (SLS) Detectors

The emphasis of our work is to incorporate enhanced functionality at the pixel level. This functionality could be information pertaining to color (spectral), polarization or dynamic range (gain). Preferred embodiments of this functionality will be highlighted using plasmonic resonators and bias dependent spectral sensors.

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7679-07, Session 2

NCI alliance for nanotechnology in cancer: new pipeline in cancer diagnostics and therapy

P. Grodzinski, National Cancer Institute (United States)

National Cancer Institute is engaged in efforts to harness the power of nanotechnology to radically change the way we diagnose and treat cancer. Novel and multi-functional nanodevices will be capable of detecting cancer at its earliest stages, pinpointing its location within the body, delivering anticancer drugs specifically to malignant cells, and determining if these drugs are effective. Functionalized nanoparticles would deliver multiple therapeutic agents to tumor sites in order to simultaneously attack multiple points in the pathways involved in cancer. Such nano-therapeutics are expected to increase the efficacy of drugs while dramatically reducing potential side effects. In vivo biosensors would have the capability of detecting tumors and metastatic lesions that are far smaller than those detectable using current, conventional technologies. Furthermore, they will provide rapid information on whether a given therapy is working as expected.

In order to further these research goals, NCI Alliance for Nanotechnology in Cancer has been formed in 2004. The Alliance is pursuing applied nanotechnologies for cancer detection, therapy, and prevention with an aim to achieve clinical translational stage of these technologies towards culmination of the program. The Alliance funds Centers of Cancer Nanotechnology Excellence, the development of nanotechnology platforms, and intramural Nanotechnology Characterization Laboratory (NCL). NCL provides a spectrum of data on the physical parameters and pharmacological and toxicological characteristics of clinically promising nanomaterials.

7679-08, Session 2

From computational chemistry to cancer targeting nanotherapeutics

K. S. Lam, UC Davis Cancer Ctr. (United States)

The one-bead-one-compound (OBOC) combinatorial library technology enables us to generate millions of compound-beads, each with unique chemical compound displayed on the bead surface. When mixed with live cancer cells, compound-beads that bind to cancer cell surface receptors are coated with a monolayer of cancer cells. The chemical structure of the compounds on the positive beads can be readily determined by direct Edman sequencing or via chemical decoding. With this approach, peptide leads that interact with a number of different cancer cells and normal cells were identified. These ligands include LLP2A, LXY3 and LXW7 that target the $\alpha 4\beta 1$, $\alpha 3\beta 1$, and $\alpha v\beta 3$ integrins, respectively. Recently, we have developed a number of amphiphilic polymers, comprised of a cluster of cholic acids (4 to 10) linked by a series of lysines and attached to one end of a linear polyethylene glycol chain (PEG, 2000-5000 Dalton). Under aqueous condition, such telodendrimers can self-assemble to form highly stable nanomicelles. We can readily load hydrophobic drugs, radionuclides, fluorochromes, quantum dots, and iron nanoparticles into the hydrophobic core of these nanomicelles. The size of the final nanocarriers (15-150 nm diameter) and their drug loading capacity are tunable depending on the size of the PEG chain and the number and arrangement of cholic acid molecules in the dendrimer. We have also demonstrated that the therapeutic efficacy and toxicity profile of our paclitaxel-loaded nanomicelles is superior to the two FDA approved formulations of paclitaxel (Taxol® and Abraxane®) in nude mice bearing ovarian cancer xenograft. Nanomicelles smaller than 64 nm preferentially targeted xenografts with high efficiency and with low liver and lung uptake, whereas those nanomicelles at 154 nm targeted the tumor poorly but with very high liver and lung uptake. Telodendrimers decorated with oligolysine or oligoaspartic acid resulted in high liver uptake. When decorated with cancer targeting ligands identified from the one-bead-one-compound (OBOC) combinatorial library methods, the drug-loaded nanoparticles were rapidly taken up by the target tumor cells causing cell death. In vivo near infra-red optical imaging studies with hydrophobic fluorescent dye demonstrated that xenograft uptake of the nanomicelles was greatly enhanced by the cancer targeting peptide. Thus far, we have been able to successfully prepare highly stable nanoformulations of paclitaxel, vincristine, SN-38 and etoposide with such telodendrimers.

7679-09, Session 2

Fabrication and testing of micro-cylindrical ion trap arrays for miniaturized mass spectrometer development

R. T. Short, F. van Amerom, A. Chaudhary, SRI St. Petersburg (United States)

The ultimate goal of SRI International (SRI) mass spectrometer miniaturization efforts is to develop a method for very cost-effective fabrication of highly sensitive miniaturized mass spectrometers. Researchers at SRI have investigated the possibility of extreme miniaturization of cylindrical ion trap mass spectrometers (CIT MSs) by using microfabrication methods, and have validated the micorfabrication approach for fabricating arrays of very small CITs (radii ≈ 0.35 mm) in silicon. Arrays of CITs operating in unison offer the possibility to recover the sensitivity losses encountered by miniaturizing individual CITs.

The approach in CIT array design has been to fabricate two identical arrays of half-CIT structures (each trap with a half-thickness ring electrode and an aperture endplate) which were then bonded back-to-back to form a full CIT array chip. Experimental data from CIT arrays demonstrated the ability to increase mass spectral sensitivity by integrating signals from individual CITs in the array. Further optimization of the CIT geometry and fabrication process produced mass spectra with better than unit mass resolution.

Computer simulations to guide fabrication processes avoid excessive manufacturing iterations by predicting optimum CIT geometries, primarily with respect to the axial-to-radial dimension ratio ($z0/r0$) and aperture size. These simulations predict optimum operating pressures for the micro-CITs that are several orders of magnitude higher than those for conventional size commercial ion trap mass spectrometers. Therefore, high vacuum pumps may not be required for mass spectrometer systems based on this technology.

7679-10, Session 2

Extraordinary magnetoresistance, piezoconductance, optoconductance, and electroconductance - or EXX phenomena in nanoscopic structures: application to imaging in biology and medicine

S. A. Solin, Washington Univ. in St. Louis (United States)

The new "EXX" phenomena in macroscopic, microscopic and nanoscopic metal-semiconductor hybrid structures will be described. Here E = extraordinary and XX = magnetoresistance (EMR), piezoconductance (EPC), optoconductance (EOC), and electroconductance (EEC). This new class of phenomena is based on the control and dominance of the geometric contributions, e.g. sample shape, lead placement, the presence of inhomogenieties, etc., to the transport properties of a physical system in contrast to traditional transport phenomena which are dominated by the intrinsic properties, e.g. mobility, carrier density, band structure, etc. The underlying phyiscs of EXX phenomena will be elucidated with particular emphasis on the use of analytic and finite element analysis methods to quantitatively account for the observed EXX signal enhancement. Surprising new aspects of the mesoscopic physics of the nano-hybrid structures will be addressed. A recently discovered inverse EOC (I-EOC) effect in which nanoscopic devices (dimensions < 500 nm) show a decrease in conductivity with increased illumination intensity with an I-EOC ~ 1000% and a specific detectivity as high as $D^* = 3.2 \times 10^{11}$ cm$\sqrt{\text{Hz}}$/W in a 250 nm device will be reported. It will be shown that I-EOC can be attributed to optical switching induced by the transition from ballistic to diffusive transport. The use of individual EXX sensors and EXX nano arrays to study, with ultrahigh spatial and temporal resolution, biologically relevant properties of cells such as surface charge density measured with a fluid-gated EEC device will be described.

7679-11, Session 2

Dynamic sampling in digital microfluidic devices

K. D. Devlin, A. Ahmadi, H. Najjaran, J. F. Holzman, M. Hoorfar, The Univ. of British Columbia (Canada)

In recent years, there has been a trend toward the development of lab-on-a-chip microfluidic devices. These digital microfluidic devices manipulate microdroplets with controlled volumes and compositions. It has been shown that digital microfluidic devices offer revolutionary technologies for numerous biological and chemical applications.

There are critical implementation challenges to consider for these new digital technologies. In dynamic applications, properties of both the system and the microdroplet are changing in time due to the adsorption of microdroplet species at the solid-liquid and liquid-vapor interfaces. An important example is protein adsorption on the surface of biochips. The analysis of such systems becomes even more complex when, for reasons of practicality and containment, the digital microfluidic architectures incorporate closed geometries, as it becomes impossible to track the position of microdroplets. In this paper, these digital microfluidic dynamic challenges are overcome through the introduction of real-time sensing submodules. Dynamic sampling has been added to the actuation mechanisms in a digital microfluidic system, and it is shown that the complete fluid system can be characterized simultaneously by

measurements of the microfluidic capacitance and the microdroplet contact angle. Analytical models are presented for the time-dependent behavior of the microdroplet properties, and the complete sampling protocol is demonstrated in a digital microfluidic prototype.

7679-12, Session 2

Applications of new carbonaceous materials

H. C. Dorn, Virginia Polytechnic Institute and State Univ. (United States); P. P. Fatouros, Virginia Commonwealth Univ. (United States)

Abstract. During the last 25 years a number of new carbonaceous nanomaterials have been discovered including fullerenes, endofullerenes, nanotubes, nanohorns, and graphene. Of special interest in this presentation is how the encapsulation of metals and non-metals in fullerenes (endofullerenes) provides new vistas in medical research. Endofullerenes, because of their shapes, capacity for multiple endo-encapsulants, isolation from the bio-environment, and exo-functionalizability, are ideal nano-constructs on which to engineer next generation diagnostic and therapeutic biomedical nanoprobes. In our VT laboratory, we have reported a family of very stable metal endohedral metallofullerenes (EMFs), A3-xBxN@C80 (x=0-3, A,B=metals) that are formed via a trimetallic nitride template (TNT) process. [1] To illustrate, in vitro and in vivo studies have demonstrated markedly enhanced 1H MRI relaxivity (~2 orders of magnitude) for functionalized gadolinium EMFs in comparison with Gd-DTPA (Omniscan), a common commercially available clinical magnetic resonance imaging (MRI) contrast agent. [2] In this presentation, we will describe the preparation, characterization, and potential medical and other related applications of these new carbonaceous nanomaterials.

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7679-13, Session 3

Office of Nuclear Proliferation's Remote Sensing Program

V. T. Franques, U.S. Dept. of Energy (United States)

In order to reduce the threat to national security posed by nuclear weapons proliferation, the National Nuclear Security Administration (NNSA) has established the Nonproliferation Research and Development (NA-22) Program Office to manage the long-term development of new and unique proliferation-detection programs. These programs encompass the development of technology for the early detection of nuclear proliferation, monitoring and analysis of nuclear weapons and materials, and the detection of nuclear weapon activities.

One of the most difficult and complex challenges across the remote sensing mission is the necessity of detecting nuclear proliferation activities where the location of the activity is unknown, or access to relevant facilities is limited or denied. Enhancing this critical need is the goal of research funded by the Remote Sensing Program (RSP.) In order to achieve this goal, the RSP supports research in three key areas:

- Expanding broad-area search-by increasing coverage and fidelity to locate and identify areas of interest.

- Increasing sensor persistence-to enable continuous surveillance of potential nuclear proliferation sites and activities.

- Enhancing identification and characterization capabilities-to remotely detect, identify, and characterize proliferation signatures.

In order to enhance the national security of the United States, the NA-22 RSP will continue to support revolutionary developments in remote sensing sensor science, technology, and engineering to service these critical needs. Developments in classical systems-level technologies such as optical, infrared and RF sensors, as well as advanced research in microsystems, photonics, and MNTs capable of standoff-detection are all considered part of this RSP mission space.

7679-14, Session 3

Laser-based sensors for chemical detection

T. L. Myers, M. C. Phillips, M. S. Taubman, B. E. Bernacki, J. T. Schiffern, B. D. Cannon, Pacific Northwest National Lab. (United States)

Stand-off detection of hazardous materials ensures that the responder is located at a safe distance from the suspected source. Remote detection and identification of hazardous materials can be accomplished using a highly sensitive and portable device, at significant distances downwind from the source or the threat. Optical sensing methods, in particular infrared absorption spectroscopy combined with quantum cascade lasers (QCLs), are highly suited for the detection of chemical substances since they enable rapid detection and are amenable for autonomous operation in a compact and rugged package. This talk will discuss the sensor systems developed at Pacific Northwest National Laboratory and will discuss the progress to reduce the size and power while maintaining sensitivity to enable stand-off detection of multiple chemicals at distances approaching one kilometer.

7679-15, Session 3

Laser-based standoff detection of surface-bound explosive chemicals

D. L. Huestis, G. P. Smith, H. Oser, SRI International (United States)

Avoiding or minimizing potential damage from improvised explosive devices (IEDs) such as suicide, roadside, or vehicle bombs requires that the explosive device be detected and neutralized outside its effective blast radius. Only a few seconds may be available to both identify the device as hazardous and implement a response. As discussed in a study by the National Research Council, current technology is still far from capable of meeting these objectives. Conventional nitrocarbon explosive chemicals have very low vapor pressures, and any vapors are easily dispersed in air. Many point-detection approaches rely on collecting trace solid residues from dust particles or surfaces. Practical approaches for standoff detection are yet to be developed.

For the past 4 years, SRI International has been working toward development of a novel scheme for standoff detection of explosive chemicals that uses infrared (IR) laser evaporation of surface-bound explosive followed by ultraviolet (UV) laser photofragmentation of the explosive chemical vapor, and then UV laser-induced fluorescence (LIF) of nitric oxide. This method offers the potential of long standoff range (up to 100 m or more), high sensitivity (vaporized solid), simplicity (no spectrometer or library of reference spectra), and selectivity (only nitrocompounds). This approach may offer the best chance for development of a practical standoff explosives detection system.

7679-16, Session 3

Long-range standoff detection of chemical, biological, and explosive hazards

A. W. Fountain III, R. G. Vanderbeek, C. R. Swim, S. D. Christesen, U.S. Army Edgewood Chemical Biological Ctr. (United States)

The US Army Edgewood Chemical Biological Center is the leader in development of military systems for chemical and biological defense, in collaboration with all Services, other Government laboratories, academia, and industry. The Departments of Defense and Army are seeking to expand their understanding towards the detection of hazardous chemicals to address the concurrent threats of toxic industrial chemicals; explosives, home made explosives or precursors; potentially illegal drugs and their precursors; in addition to traditional chemical and biological warfare agents. Unique capabilities, state-of-the-art sensors, and emerging technologies are under development for chemical, biological, and explosives detection. Updated results will be presented on standoff biodiscrimination using infrared (IR) depolarization lidar and long-wave IR (LWIR) lidar, as well as surface chemical detection via Raman spectroscopy and a new initiative extending detection to Unknown Bulk Explosives (UBE).

7679-17, Session 4

An overview of ONR nano-electronics program

C. Baatar, Office of Naval Research (United States)

In this talk I will briefly describe the Nanoscale Electron Devices and Sensors program at the Office of Naval Research. I will describe the current scope and future vision for the program. Will draw examples from recent projects to give audience a flavor of the research that is being done under the sponsorship of ONR and also gauge progress towards realizing the program vision. New research focus areas such as graphene and DNA nano-assembly will be specially emphasized.

7679-18, Session 4

Micro (and nano) mechanical signal processors

S. A. Bhave, Cornell Univ. (United States)

With quality factors (Q) often-exceeding 10,000, vibrating micromechanical resonators have emerged as leading candidates for on-chip versions of high-Q resonators used in wireless communications systems. However, as in the case for transistors, extending the frequency of MEMS resonators generally entails scaling of resonator dimensions. Unfortunately, smaller size often coincides with lower-power handling capability and increased motional impedance. In this talk, I will introduce novel transduction techniques which can improve the motional impedance of MEMS resonators by 1000X over traditional 'air-gap' transduced resonators, present latest results on narrow-bandwidth parametric filters for frequency-agile radio receivers, and discuss performance scaling of NEMS resonators to X-band frequencies.

7679-19, Session 4

Sensitivity enhancement of vapor sensors with porous silicon resonant structures

R. N. Candler, Y. Hwang, F. Gao, Univ. of California, Los Angeles (United States)

Miniaturization of gravimetric-based sensors is a promising strategy for chemical detection due to scaling advantages. The increased surface area-to-volume ratios at the micro- and nano-scale can lead to improved sensitivities, with challenges at these scales relating to fabrication, functionalization, and signal detection. Previous work investigated porous coatings for enhancement of surface area (and therefore sensitivity) of gravimetric, deflection-based, and optical chemical sensors. We will describe our efforts in creating entire structures made of porous silicon and their use as resonant vapor detectors. Potential areas of application include explosives detection and environmental monitoring.

7679-20, Session 4

Defense applications of carbon-based nanomaterials

E. Snow, U.S. Naval Research Lab. (United States)

Because it possesses extraordinary electrical, mechanical and chemical properties, graphene represents an increasingly important material in nanotechnology. These extreme properties combined with recent advances in wafer-scale production open the possibility of a number of DOD applications.

In this presentation I will present results obtained at NRL on the formation and use of wafer-scale films of graphene for sensor, nanoelectromechanical and RF device applications. We have investigated graphene formed by thermal decomposition of SiC, CVD-grown graphene and films of chemically modified graphene. Our initial results are encouraging and indicate that graphene has a promising future for both electronic and sensor applications.

7679-21, Session 4

Organic MEMS devices and MWCNT interconnects

B. Lempkowski, Motorola, Inc. (United States)

Organic MEMS devices are fabricated from typical resin-based PCB (printed circuit board) dielectrics, copper sheets, and adhesives in a laminated structure, with the addition of a few process steps to selectively add a sacrificial material to allow a free-standing MEMS structure when completed. This construction was used to develop production size panels with high device counts of varieties of single and multi-throw switch styles, compatible with embedded passive components for RF front end integration. Test data will be shown and discussed for organic MEMS switches, switch-filter banks, and a varactor design with exceptional tuning bandwidth. Anticipating future integration, conductive multi-wall carbon nanotubes (MWCNT) were investigated from an interconnect to the larger world perspective of organic MEMS as opposed to the SWCNT device interconnect domain. MWCNT tapes and ribbons were used to determine and benchmark current losses in microstrip compared to copper equivalents. In addition, a PIFA antenna (planar inverted F) was also constructed to compare against its copper equivalent at this time. These MWCNT components were mounted on typical resin-based PCB and results will be shown.

7679-22, Session 4

Carbon-based nanoelectromechanical systems

A. B. Kaul, A. R. Khan, K. G. Megerian, L. C. Bagge, L. W. Epp, Jet Propulsion Lab. (United States); A. T. Jennings, J. R. Greer, California Institute of Technology (United States)

The microelectronics industry based on Si transistors continues to push the limits on scaling, which has created unique opportunities for nanoscale materials, such as carbon nanotubes (CNTs). An important application of CNTs is in nano-electro-mechanical-systems (NEMS) that has the potential to overcome the limitations of Si transistors as a result of shrinking device dimensions. We will describe our work on 3D carbon-based NEMS, where nanomanipulation was used actively to determine the electrical characteristics of individual, as-grown, vertically-oriented tubes, and suggests such structures have promise in nonvolatile memory applications. Beside the electrical characteristics of our 3D NEMS switches, we will also present the results of nanomechanical measurements on individual as-grown tubes, and the finite element models that were developed for the switches. Finally, we will provide a brief overview on the modeling and characterization of high frequency mechanical resonators derived from vertically oriented tubes.

7679-23, Session 5

Opportunities in basic research for battlefield sensing

J. J. Becker, U.S. Army Research Office (United States)

Battlefield sensing is a complex, crucial tool that allows the soldier to sense/detect potential threats in order to maintain a safe environment. Its technological development is typically driven by a myriad of field requirements. A variety of chemical sensing technologies currently exist, and there are also many prospects for the development of new, revolutionary technologies. This talk will focus on current needs and requirements in chemical sensing, in addition to some of the current technologies used and the challenges related to development of new technologies. Basic research opportunities relevant to chemical sensing in these harsh environments will be presented.

7679-24, Session 5

Enzyme-polymer based environmental monitors

K. LeJeune, ICx Technologies (United States)

Enzymes are commonly used as the active element in chemical sensors because of their analyte specificity, sensitivity, and the speed with which they catalyze reactions. Their precision and reliability has them at the core of many FDA-approved medical diagnostic tests. Unfortunately, nature has evolved most enzymes to operate under a fairly narrow range of storage and operating conditions (i.e. pH, ionic strength, temperature, organic content, etc). The deployment of enzyme-based sensors in poorly controlled environments with fluctuating conditions can therefore be difficult.

ICx Technologies has sought to minimize the impact of environmental parameters on enzyme catalysis through enzyme polymerization. Rather than being simply immobilized onto an existing substrate, enzymes are used as co-monomers with other conventional monomers in polymerization reactions. Enzymes are incorporated within the polymer through multiple covalent attachments. By essentially anchoring the enzyme's tertiary structure, the polymerization process stabilizes enzyme sensitivity to many environmental factors. ICx has built chemical sensors using enzyme polymers, some of which continuously monitor air or water in real time. The performance of these instruments will be discussed in terms of analyte sensitivity and the impact of varied environmental conditions.

7679-25, Session 5

AlGaN/GaN high-electron mobility transistor-based sensors for environmental and bio-applications

F. Ren, B. Chou, K. H. Chen, Y. Wang, C. Y. Chang, S. J. Pearton, Univ. of Florida (United States); A. M. Dabiran, P. P. Chow, SVT Associates, Inc. (United States)

It is highly desirable to have a programmable, single chip sensor with an array of sensors for different purposes that is handheld and capable of wireless communication. This kind of sensor can be very useful for environmental, safety, and biomedical applications. AlGaN/GaN high electron mobility transistors (HEMTs) have shown promise for bio-sensing applications, since they include a high electron sheet carrier concentration channel induced by piezoelectric polarization of the strained AlGaN layer. There are positive counter charges at the HEMT surface layer induced by the electrons located at the AlGaN/GaN interface. Any slight changes in the ambient can affect the surface charge of the HEMT, thus changing the electron concentration in the channel at AlGaN/GaN interface. We have demonstrated AlGaN/GaN HEMT based individual sensors for protein, DNA, kidney injury molecules, prostate

cancer, pH values of the solutions, pH in the exhaled breath condensate, and mercury ions with specific surface functionalizations.

7679-26, Session 5

Ultra-high sensitivity CO sensor based on nanocrystalline metal oxide gate AlGaN/GaN heterostructure

S. A. Eliza, R. Olah, A. K. Dutta, Banpil Photonics, Inc. (United States)

This paper presents a robust sensor to detect low concentration (<1 ppm) of CO gas. The sensor is based on AlGaN/GaN Metal-Oxide-Semiconductor High Electron Mobility Transistor (MOS-HEMT) with a non-conventional gate structure. The performance of the sensor has been simulated based on the charge control physics of AlGaN/GaN heterostructure transistor. Large sensitivities and widely linear characteristics are obtained for the AlGaN/GaN device based sensor assuming ideal gas-surface kinetics which can be approximated by the proposed gate structure.

Detection of CO has been reported using the conductive property of metal-oxides films and nanoparicles. To amplify the current, three-terminal solid-state sensors based on metal-oxide gated Si FETs have been constructed. However, Si FETs have the limitations in intrinsic properties compared to wide bandgap semiconductor devices. AlGaN/GaN based wide bandgap devices have become very attractive for detection of chemicals, gases, liquids or biomolecules. The enhanced mobility due to modulation doping and polarization induced high density two-dimensional electron gas at the heterointerface in GaN results in large sensitivities of the device. This work presents for the first time a highly selective and sensitive two terminal CO sensor using metal-oxide (SnO_2) gated AlGaN/GaN HEMT device. The gate comprises of a nanocrystalline SnO_2 layer deposited on a thin layer of SiO_2. A nanoporous metal layer layer has been used on the metal-oxide. For nanometer size grain boundaries in SnO_2 and the addition of metallic catalytic layer, strong absorption of CO can be achieved at room temperature. Deails result will be presented in the Conference.

7679-27, Session 5

The development of micro/nano chemical sensor systems for aerospace applications

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Aerospace applications require a range of chemical sensing technologies to monitor conditions re-lated to both space exploration and aeronautic aircraft operations. These applications include leak detection, fire detection, engine emissions monitoring, human health monitoring, and environmental monitoring. This paper discusses efforts to produce microsensor platforms that can be tailored to measure a range of chemical species. This technology development ranges from evaluation of more mature systems in relevant environments to basic material development and sensor processing. An example of a more mature system is "Lick and Stick" technology: smart sensor systems which include signal conditioning, data processing, power conditioning, and communication in a compact structure near the surface area of a postage stamp. This Smart Sensor System is meant to be a platform which can be flexibly tailored to meet broad application needs and integrated into vehicle systems as required using a range of MEMS (Micro-Electro-Mechanical Systems) based sensor technology. In contrast, an example of basic material development and sensor processing is the development of metal-oxide nanostructures (such as tin oxide) for

chemical sensing applications. While nanocrystalline materials have previously been developed, the advantages of nanostructured oxide sensors, such as nanowires, are just beginning to be explored. Significant technical challenges remain toward standard implementation of these nanostructures in sensing applications including integration of the nanowires into sensor structures. It is concluded that while microsensor systems can have a significant impact on aerospace applications, they vary in their level of maturity and extensive application testing is necessary for their long-term implementation.

7679-28, Session 5

Silicon carbide radiation micro-detectors for harsh environments

G. Bertuccio, Politecnico di Milano (Italy)

Silicon Carbide (SiC) is a wide bandgap semiconductor with outstanding physical properties for manufacturing detectors of ionizing radiation (alpha, electrons, protons, X-rays,...). The wide band gap (up to 3.2 eV), high saturation velocities of the charge carriers($2x10^7$ cm/s), high breakdown field (2 MV/cm), high thermal conductivity (4.9 W/cm²) and its radiation hardness, allow low-noise operation in environments critical or forbidden to other semiconductor detectors such as Si, GaAs, CdTe, CdZnTe.

In the last ten year considerable R&D efforts have been devoted worldwide to growth and process technologies which have made available high purity epitaxial SiC 3" wafers. The state of the art of SiC micro-detector manufacturing technology will be presented together with prototype detectors with high resolution spectroscopic capabilities and outstanding low noise performance at room and high temperature.

The present research activities on SiC for radiation detection, spectroscopy and imaging will be presented and the radiation hardness of SiC will be discussed. Experimental results on several detector types (pad, pixel, microstrip) and associated readout electronics will be shown. The necessity and the limits of ultra-low noise front-end electronics for reading out the almost noiseless SiC detectors will be highlighted. Soft X-ray spectroscopy with energy resolutions of 113 eV (6 e- r.m.s.) and 163 eV FWHM (9 e- r.m.s.) with SiC pixel detectors operating at +30°C and +100°C, respectively, will be presented. The present research efforts and perspectives for SiC radiation detectors development will be finally discussed.

7679-29, Session 5

GaN-based high temperature and radiation-hard electronics for harsh environments

K. Son, A. Liao, G. Lung, M. Gallegos, R. D. Harris, L. Z. Scheick, W. D. Smythe, Jet Propulsion Lab. (United States)

We develop novel GaN-based high temperature and radiation-hard electronics to realize data acquisition electronics and transmitters suitable for operations in harsh planetary environments. III-nitride (GaN/AlxGa1-xN) compound semiconductor materials have large band gaps (3.4 - 6.0 eV) and strong atomic bonds, and they exhibit strong thermal, mechanical, and chemical stabilities and radiation hardness. Thus they are ideal materials for extreme and harsh environment electronics. In this paper, we will discuss our research on GaN metal-oxide-semiconductor (MOS) transistors that are targeted for 500 °C operation and >2 Mrad radiation hardness. For the target device performance, we develop innovative Schottky-free, normally-off GaN MOS transistors, where a gate electrode is processed in a MOS layout using an atomic-layer-deposition grown oxide gate dielectric layer. The GaN MOS transistors fabricated with the wide-bandgap gate oxide layer enable Schottky-free gate electrodes, resulting in a much reduced gate leakage current and an improved sub-threshold current than the current GaN field effect transistors. Therefore the high temperature-induced gate burnout, the primary cause of device failure at high temperatures, can be prevented with the GaN MOS transistors. In this study, characterization of our

GaN MOS transistors is carried out over the temperature range of 25°C to 500°C. Ids-Vgs and Ids-Vds curves are measured as a function of temperature to investigate temperature-dependent transconductance, ohm resistance in linear I-V region, and saturation current. Radiation hardness testing of the GaN MOS transistors is performed using a 50 MeV 60Co gamma source to explore effects of TID (total ion dose). Radiation tests are performed with both biased (in operation) and unbiased devices using the radiation dose of 25rads/s up to 2MRads TID.

7679-30, Session 6

Power considerations for MAST platforms

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The U.S. Army Research Laboratory's Micro Autonomous Systems & Technology (MAST) program is focused on developing autonomous mobile Microsystems to enhance tactical awareness in urban and complex terrains. Such systems are projected to be palm sized and smaller to provide a combination of stealth and accessibility to restricted areas. The scaling down of autonomous systems introduces numerous challenges, but none are more difficult to scale than the power system. Lithium polymer batteries or emerging thin film batteries [1] often provide sufficient power density (10-100+ W/kg [2-3]) for a primary source, while augmentation with energy scavengers is often discussed to increase energy density. However, our survey of MAST systems in development revealed that significant challenges remain on the power distribution side, where the desired currents & voltages change by orders of magnitude depending on the function of a particular sub-system (mobility, sensing, communication, etc). Thus, a mobile microsystem must carry both a tiny power dense source and a vanishingly small, ultra efficient power converter capable of operating across multiple orders of magnitude. To this end, we are working to develop novel power conversion and management systems at the cubic-millimeter, milligram scale. Our technical approach is three-fold: (1) Development of CMOS converter topologies that operate at high frequency (100-500MHz vs 1-10MHz). (2) Leverage microelectromechanical systems (MEMS) techniques to microfabricate ultra-miniature passive components integrated with ferroelectric or ferromagnetic nanoparticles. (3) Investigation of piezoelectric-based MEMS resonant transformers for point of use conversion. Progress in each of these three areas will be discussed.

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7679-31, Session 6

Circuit design advances for ultra-low power sensing platforms

D. Sylvester, D. Blaauw, S. Hanson, G. Chen, D. Kim, M. Fojtik, M. Seok, Y. Lin, Univ. of Michigan (United States)

This work describes new integrated circuit building blocks for emerging wireless sensing applications, particularly those where volume, and therefore power consumption, constraints are orders of magnitude below current state of the art. Developments in sub-nW timekeeping circuits are described, along with extremely low leakage memories and efficient DC-DC voltage conversion circuits at μA-level current loads. Taken together, these circuit design advances point to a vision of true mm^3 low-cost sensing nodes with hybrid power sources, i.e., scavenged + microbattery, providing long lifetimes and reliable operation.

7679-32, Session 6

Design of power sources for micro-autonomous systems

S. R. Narayan, A. Kisor, H. M. Manohara, L. H. Matthies, Jet Propulsion Lab. (United States)

Micro-autonomous systems with very severe mass and volume constraints present significant challenges to the design of power sources that meet the minimum endurance (duration) requirements of a wide range of operational scenarios . State-of-art power sources do not meet the projected mission requirements. This paper will explore the design opportunities provided by multifunctional integration concepts, various types of high energy power sources, hybrid power management concepts, energy harvesting concepts, and smart operational strategies that are applicable to the scale of micro-autonomous systems. The analysis provided in this paper will assist in identifying the specific directions for future research and development for powering micro-autonomous systems. The discussion will be driven by basic system analyses and sizing models for micro ground and air vehicles in the size range from a few 10s of grams to roughly 500 grams. Legged, wheeled, and tracked ground platforms will be considered, as well as fixed and rotary wing air vehicles. Nominal mission scenarios will include outdoor/indoor urban settings and underground scenarios.

7679-33, Session 6

Flexible solar cell technology for micro-autonomous systems technology

L. F. Lester, K. Yang, M. A. R. El-Emawy, T. Saiz, The Univ. of New Mexico (United States)

Recent interest in using InAs quantum dots (QDs) in solar cells has focused primarily on the predicted increase in quantum efficiency due to the intermediate band effect or simply larger short circuit current density. However, the three-dimensional carrier confinement inherent to QDs endows them with unique carrier transport capabilities that have not been previously explored in the context of solar cells. In this work, it is observed that InAs/InGaAs dots-in-a-well (DWELL) structures efficiently suppress lateral carrier diffusion. Therefore, not only do the DWELL structures enhance photocurrent by extending the absorption edge, but they should also inhibit the spreading of current to the perimeter of a device where edge recombination can dominate. This attribute is attractive for flexible solar applications where an integrated array of very small area cells is desirable. In this paper, we examine this premise by comparing the dark current behavior of DWELL cells and GaAs control cells of varying area before and after mounting on flexible substrates such as nanopaper and KAPTON. The lower open-circuit voltage in the smaller GaAs control cells is caused by strong Shockley-Read-Hall (SRH) recombination on the perimeter, which leads to a shoulder in the semi-logarithmic dark IV curve. However, despite the fact that the DWELL and GaAs control cells were processed simultaneously, the shoulders on the dark IV curve disappear in all the DWELL cells over the whole processed wafer. The results are promising for applications where shrinking the size of the device while maintaining high charge collection efficiency are of paramount importance.

7679-34, Session 6

Systematic study of the performance of small robots on controlled laboratory substrates

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The DASH and RoACH robots are small (~10 cm long, and ~20 g mass) six legged biologically inspired robots fabricated using the smart composite microstructure (SCM) process which makes them robust to environmental changes. Although these robots must locomote effectively over a diversity of ground, detailed ground interaction models which would allow predictive design are lacking. Therefore, we examine systematically under open loop control their performance on both substrates that are rigid and substrates like sand that can yield and flow like a fluid in response to foot penetration. Varying both ground properties and limb stepping frequency, we measure average running speed, cost of transportation (power consumption) and stability. We find that performance and stability of these devices is sensitive to the physics of ground interaction: on hard ground inertia must be managed to prevent yaw, pitch and roll instability to maintain high performance, while on sand the fluidizing interaction leads to increased cost of transport and lower running speeds. We also observe that the unique limb morphology and kinematics of each robot result in its distinct capability/inability to traverse different terrains. Our systematic studies are the first step toward developing models of interaction of limbs with complex terrain as well as developing improved limb morphologies and control strategies.

7679-35, Session 6

MAV endurance versus battery size

D. W. Beekman, U.S. Army Research Lab. (United States)

Micro Air Vehicles (MAVs) operate with many inter-related constraints, including size, weight, power, processing, and communications. Simple models can be used to provide initial estimates of subsystem parameters that are consistent with the targeted size and related parameters. For most current MAVs, the power source of choice is batteries, and the choice of battery type and size will determine the maximum duration of a flight. In this study, a first order model is used to determine the optimum battery size for maximum endurance, given typical values for related parameters of a 15-cm scale MAV.

Basic helicopter equations are used along with battery specific energies and system parameters to determine that most MAV researchers (at least those on the ARL MAST program) are using battery sizes significantly different than optimum.

7679-36, Session 6

A design process for robot capabilities and missions applied to micro-autonomous platforms

Z. Kira, R. C. Arkin, T. R. Collins, Georgia Institute of Technology (United States)

As part of our research for the ARL MAST CTA (Collaborative Technology Alliance), we present an integrated architecture that facilitates the design of microautonomous robot platforms and missions, starting from initial design conception to actual deployment. The framework consists of four major components: design tools, mission-specification system (MissionLab), case-based reasoning system, and a simulation environment (USARSim). The designer begins by using design tools to generate a space of missions, taking broad mission-specific objectives into account. For example, in a multi-robot reconnaissance task, the parameters varied include the number of robots used, mobility capabilities (e.g. maximum speeds), and sensor capabilities. The design tools are used to intelligently carve out the space of all possible parameter combinations to produce a smaller set of mission configurations. Quantitative assessment of this design space is then performed in simulation to determine which particular configuration would yield an effective team before actual deployment. MissionLab, a mission-specification platform, is used to incorporate the input parameters, generate the underlying robot missions, and control the robots in simulation. It also provides logging mechanisms to measure a range of quantitative performance metrics, such as mission completion rates, resource utilization, and time to completion, which are then used to

determine the best configuration for a particular mission. These metrics can also provide guidance for the refinement of the entire design process. Finally, a case-based reasoning system allows users to maximize successful deployment of the robots by retrieving proven configurations and determine the robot capabilities necessary for success in a particular mission.

7679-37, Session 7

Silicon microcell photovoltaics

J. A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Silicon, in amorphous or various crystalline forms, is used in >90% of all installed photovoltaic (PV) capacity. The high natural abundance of silicon, together with the excellent reliability and good efficiency of solar cells made with it suggest its continued use, on massive scales, for the foreseeable future. In this talk, we describe some new ways to use this relatively old material, in the form of micro-cells created from bulk wafers and integrated in diverse spatial layouts on foreign substrates by transfer printing. The resulting devices can offer useful features, including high degrees of mechanical flexibility, user-definable levels of transparency and ultra-low profile micro-optic concentrator designs. Detailed studies of the processes for creating and manipulating such micro-cells, together with investigations of the electrical, mechanical and optical characteristics of several types of modules that incorporate them illuminate the key aspects. The results represent strategies that might expand the application possibilities for monocrystalline silicon PV.

7679-38, Session 7

Fully printed batteries for flexible electronics: materials and processing challenges and opportunities

D. A. Steingart, The City College of New York (United States)

Flexible electronics require flexible energy storage, and electrochemical batteries are currently the strongest option for such devices. Unfortunately, batteries are fundamentally microscale mass transport dependent reactors with a strong coupling between mechanical stress and device performance. In order to create batteries that meet required performance metrics for this new class of devices, the fundamental interactions between electrochemically active materials, processing, and device geometry have to be re-examined. The presented work will explore basics of printed electronics, materials that are already used in flexible electronics that can be repurposed as active battery components, and materials that are compatible with flexible electronics processing. Novel methods of determining mechanical properties of printed materials in-battery will be also be examined. Microfluidic channels are formed around printed battery electrodes, allow in-situ measurement of electrode cycling behavior (color change, volume change, erosion, etc) by varying electrolyte flow rate and composition. Electrodes over silver, silver-oxide, zinc (both plated and printed) and manganese oxide will be demonstrated. Flow rate will be correlated with electrode shear strength and cell cycle life.

7679-39, Session 7

Self-powered system-on-chip (energy chip)

M. M. Hussain, King Abdullah Univ. of Science and Technology (Saudi Arabia)

In today's world, we are struggling with power generation to meet up the ever increasing need for power consumption. Consumer driven technology wants the more portable electronic gadgets to be developed and marketed sooner than later. Same as direct civilian applications, defense, space, petroleum industries, ocean exploration also need

Systems-on-Chip (SoC) (Energy Chip) which will reduce power consumption as well as will harvest and store enough energy to supply sufficient power to run that SoC. This idea may not be novel in the macro world, however, to materialize such a technical goal requires several critical challenges to be overcome which include by not limited to:

(i) Nano-maachining: nanofabrication of macro/micro systems which transports the direct benefit of light weight (thus portability), low power consumption, faster response, higher sensitivity and batch production (hence low cost).

(ii) Integration of advanced nano-materials: various nano-materials are now being developed, synthesized or critically examined by scientific community and technologically matured semiconductor industries to keep their Moore's Law rolling to meet the performance/cost benefit trend. Nano-materials may offer new functionalities which were previously underutilized from macro/micro dimension.

(iii) Power efficiency: as it is stated earlier, to concurrent challenges need to be met to achieve the power efficiency - reduce power consumption and harvest (generate) plus supply that to meet the power demand.

In the newly established, King Abdulla University of Science and Technology (KAUST) to realize the vision of its founder King Abdullah and to meet the 21st century challenges, in our Integrated Nanotechnology lab we are conducting research to build self-powered transistors where we use the dissipated heat to convert them to usable energy (with the shrinking size of transistor, we are moving towards faster switching at the cost of higher leakage consequently more power dissipation in heat form). We are also working on a platform development which can host nanowire based solar cell, piezoelectric generator , storage (battery) to host a sensor (ultimately the platform should be able to host any compatible sensor irrespective of its application) and a wireless communicator with required control/power conditioning circuitry consisting of self-powered transistors to nano-electro-mechanical (NEM) switching. We are working with our collaborators in Stanford University and Georgia Tech. Partnering with Cornell University we are investigating tunable materials like Nano-ionic-materials (NIMS) . For immediate application, we are working with Penn State University to explore micro-bio-fuel cells (as fuel cell integration can bring a new dimension to the current Self-powered SoC work). In the SPIE DSS10 Micro-Nanotechnology Sensors, Systems, and Applications Conference at Advanced Micro-Nano Energy Generation and Storage Session, we will be presenting our theoretical (modeling and simulation) work with some initial experimental results to give insight and to stimulate discussion on this topic.

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7679-40, Session 7

Multifunctional carbon nano-architectures as designer platforms for electrochemical power sources

J. W. Long, M. B. Sassin, U.S. Naval Research Lab. (United States); C. N. Chervin, J. M. Wallace, K. A. Pettigrew, Nova Research, Inc. (United States); J. L. Dysart, D. R. Rolison, U.S. Naval Research Lab. (United States); A. N. Mansour, Naval Surface Warfare Ctr. Carderock Div. (United States)

We use fiber-paper-supported carbon nanofoams as the basis for "multifunctional electrode nanoarchitectures" in which the nanofoam serves as a conductive, ultraporous scaffolding for subsequent incorporation of electroactive functionalities such as metal oxides, metal nanoparticles, and ultrathin polymers. The resulting functionalized carbon nanofoam papers are designed to serve as "plug-and-play" electrode structures in electrochemical devices ranging from high-rate Li-ion batteries and electrochemical capacitors to metal-air batteries and fuel cells. For electrochemical capacitor applications, we have developed self-limiting electroless deposition protocols to generate conformal, nanoscopic coatings of either manganese or iron oxides on the exterior and interior surfaces of carbon nanofoams. The nanoscopic morphology of the metal oxide enables charge-storage capacities that are higher than typically observed for the respective oxides used in conventional composite electrode structures, while the nanoarchitecture design itself facilitates rapid charge-discharge of the oxide coating. The MnOx-carbon and FeOx-carbon nanofoam structures function as complementary electrodes (positive and negative, respectively) in asymmetric aqueous electrochemical capacitors that enable operating voltages approaching 2 V, and deliver an optimal combination of power and energy densities within a 1-100 s charge-discharge timeframe. In related work, functionalized carbon nanofoam papers are used as air-cathodes for metal-air batteries, in which the nanoscopic oxide coating (in particular manganese oxide) enhances electrocatalytic turnover for molecular oxygen reduction. En route to practical high-performance energy-storage and conversion devices, these multifunctional nanoarchitectures also serve as convenient platforms with which to investigate fundamental electrochemical processes at nanoscale interfaces using a variety of spectroscopic techniques.

7679-41, Session 7

Embeddable micro-solid oxide fuel cells for portable power

S. Ramanathan, Harvard Univ. (United States)

Micro-solid oxide fuel cells that are scalable and low-cost manufacturable are important as niche high-energy density power sources as well as enabling clean energy technologies. In this presentation, I will discuss our on-going efforts in experimental demonstration of embeddable micro-solid oxide fuel cells for portable energy. Large arrays of solid oxide fuel cells fabricated by lithographic processing on silicon platforms will be presented as well as a detailed study on their performance as a function of operating temperature. Further, we will present recent results on novel approaches to enable large area membranes that are necessary for scaling the power output. Unique experimental approaches and instrumentation developed to characterize the component nanostructured materials will be highlighted. Subsequently, we will discuss scientific themes in nanoscale ionic transport, interface-driven conductance changes in multi-component oxides and potential for exploiting interface phenomena in advanced energy conversion and generation applications.

7679-42, Session 7

MEMS for micro-power sources: self-pumping fuel cells and 3D batteries

C. Kim, Univ. of California, Los Angeles (United States)

As two distinctive types of micro power sources enabled by MEMS technologies, a micro fuel cell and a micro battery are presented. (1) Demonstrated for a micro direct methanol fuel cell (μDMFC), the developed fuel-cell architecture requires neither an ancillary pump nor a gas separator, preventing the so-called packaging penalty that has been hampering the fuel-cell miniaturization. The fuel circulation is visually confirmed, and the effectiveness for fuel cell applications is verified during the continuous operation of a μDMFC. Different from common pump-free fuel delivery approaches, the reported mechanism delivers the fuel "actively" and does not depend on gravity. (2) Demonstrated as a zinc-air micro battery, the developed battery architecture uses three-dimensional electrodes, as opposed to the conventional thin-film electrodes, producing much higher energy and power per given footprint area. The performance is reported and compared with the commercial miniature zinc-air batteries. The 3D micro battery is especially useful when the area available for batteries is limited, e.g., to power micro devices. The emphasis will be on the fabrication technologies over electrochemistry.

7679-43, Session 8

Nanoscale semiconductor materials: challenges and opportunities for electronics and sensors

A. Javey, Univ. of California, Berkeley (United States)

Large-scale assembly of highly ordered, dense, and regular arrays of nanowires (NWs) with high uniformity and reproducibility through a simple contact printing process is described. This printing approach enables large-scale integration of NW arrays for various device and sensor structures on both rigid and mechanically flexible substrates. The potency and versatility of the method is further demonstrated by large-scale, heterogeneous integration of NWs for image sensor circuitry by utilizing optically active NW sensors and high mobility NW transistors. The NW sensors and electronic devices are interfaced to enable an all-NW circuitry with on-chip integration, capable of detecting and amplifying an optical signal with high sensitivity and precision. The ability to interface NW sensors with integrated electronics on large scales and with high uniformity presents an important advance toward the integration of nanomaterials for sensor applications. Additionally, the use of 3D structures for efficient and cost effective PVs is discussed. In this regard, we have recently reported the direct growth of highly regular, single-crystalline nanopillar (NPL) arrays of optically active semiconductors on aluminum substrates which are then configured as solar cell modules. As an example, we have demonstrated a PV structure that incorporates 3D, single crystalline n-CdS NPLs, embedded in poly-crystalline thin films of p-CdTe, to enable high absorption of light and efficient collection of the carriers. Through experiments and modeling, we demonstrate the potency of this approach for enabling highly versatile solar modules on both rigid and flexible substrates with enhanced carrier collection efficiency arising from the geometric configuration of the NPLs.

7679-44, Session 8

Sensing with locally self-assembled 1D nanostructures

O. Englander, Florida State Univ. (United States)

One-dimensional nanostructures have attracted considerable interest as potential building blocks and functional components in next generation nanoscale sensing, NEMS, circuits, and interconnect applications. In recent years, research efforts have focused on the synthesis and characterization of a wide range of one-dimensional (1D) nanostructures. With the wealth of well-characterized nanostructures and well-formulated processes to control material properties, demonstrations of nanoscale devices, particularly, sensing applications have become commonplace.

While various methods for the integration of 1D nanostructures into sensing frameworks exist, here we will explore nanoscale sensor configurations realized by the localized self-assembly and site-specific integration of the nanostructures. This approach is highly compatible with standard fabrication techniques, eliminates cumbersome contact formation steps and may present a viable option for large scale manufacturing of nanoscale systems. The use of this assembly technique for sensing using carbon nanotubes and inorganic nanowires has been demonstrated. In particular, gas, pressure, UV and bio sensing applications have been explored. The novel use of self-assembled 1D protein nanofibers in sensing applications will also be highlighted. Finally, we will assess the implications of the assembly technique on nanostructure properties, interfacial properties and system-level characteristics.

7679-45, Session 9

Synthesis and characterization of highly responsive transducer materials

J. Q. Lu, Univ. of California, Merced (United States)

We have designed and synthesized a brand new alternating polymer system which can be easily processed into the thin film format. The prepared films contain nanoscale domains resulting from the self-assembly of two dissimilar polymer segments. The hard domains that contain molecular light switches are crosslinked and are surrounded by a matrix composed of soft polymer. The collective bending of molecular light switches in the hard domains upon light stimulation will cause film coiling and flating out reversibly. The matrix melting temperature has been tuned to be close to room temperature. Therefore the soft matrix can be regarded as a thermal switching element while the hard domains act as netpoints to maintain overall film integrity. Small temperature fluctuations around room temperature will melt and solidify the matrix, generating extremely large strokes.

To further enhance their response time and mechanical integrity, we have investigated the effect of covalent coupling between 1D nanomaterials, such as carbon nanotubes, and the responsive polymer on light and heat responsiveness in terms of cycle time and amplitude. The new nanohybrids combining the highly deformable features of polymeric materials with emergent properties of 1D nanomaterials will lead to revolutionary transducer materials for sensing, actuation and energy harvesting.

7679-46, Session 9

Fabrication of hybrid nanostructures for sensor applications

P. M. Ajayan, Rice Univ. (United States)

The talk will focus on approaches used to engineer materials at the nanoscale for various applications in future technologies. In particular, the case of carbon nanotubes will be used to highlight the challenges and progress. Various organized architectures of nanotubes and their hybrids can be fabricated using relatively simple processes and the work in attaining control on the directed assembly of these structures will be discussed. Some of these structures offer excellent opportunity to probe novel nanoscale behavior; however, when it comes to engineering such materials into precise architectures, challenges remain. We have pursued several novel applications for these materials, taking into account their multifunctional properties. Some of these promising applications of nanotubes and nanotube-hybrids, such as sensors, will be reviewed from the perspective of what has been accomplished in recent years. Our efforts on the strategies of growth and manipulation of nanomaterials and some of our recent successes in controllably fabricating heterogeneous and complex nanostructures will be highlighted.

7679-47, Session 9

Tunneling junctions as molecular sensors

N. Prokopuk, Naval Air Warfare Ctr. Aircraft Div. (United States); K. Son, Jet Propulsion Lab. (United States)

Electron tunneling provides a mechanism for transducing the presence of a molecular analyte into an electrical signal. The rate of electron tunneling between a donor and acceptor is highly dependent on the electronic properties of the intervening medium. Small changes in the chemical composition or molecular structure of this intervening material can result in substantial changes in the electronic coupling between the donor and acceptor and significant variations in the tunneling currents. Nanospaced electrodes provide an experimental platform for directly translating the presence of a molecular species into an electrical response by probing the tunneling currents through molecular ensembles. Vacant crossbar junctions were fabricated with nanometer separations using a combination of electron-beam lithography and selective chemical etching. The resulting structures consist of overlapping gold wires with well defined separations that are on the order of a few nanometers. As gaseous analytes infiltrate the space separating the electrodes, the tunneling currents across the gaps increase. These currents are dependent on the concentration and type of analyte. Kinetic effects also play a roll in determining the electrical response of the junctions. These

studies demonstrate that the tunneling junctions are effective tools for detecting molecular analytes.

7679-48, Session 9

Enhanced field ionization/desorption on branched silicon nanowires: applications in gas ionization detection

R. Banan Sadeghian, M. S. Islam, Univ. of California, Davis (United States)

We recorded anomalous gaseous field-ionization, field-desorption, and discharge on branching intrinsic silicon nanowires grown by a two-step VLS technique. Small branches, about 10 nm in diameter, were formed on the primary Si (111) nanowires by re-flowing SiH4 into the CVD chamber after an intermediate annealing treatment in HCl ambient. A flat aluminum slab (cathode) was mounted d = 60µm above the nanowires using a patterned polypropylene thin film as a spacer with gas channels. Field-ionization and field-desorption I-V curves of argon, nitrogen and ammonia, were recorded individually within a wide pressure range (10^{-7} to 10 Torr). Field ionization initiated at sub volt was followed by field desorption at about 2-20V (applied field of ~ 3×10^2 to 3×10^3 V/cm). Such voltages are three orders of magnitude smaller than the applied voltages required to generate field ionization on sharp metallic tips having the same tip curvature. The measured I-V curves were pressure dependent, particularly in the field ionization regime. Low voltage filed ionization and desorption phenomena were attributed to the combination effects of geometrical field enhancement on the apex of nanoscale silicon branches, the surface states formed by the gold catalyst, and the gold nanoparticles themselves. The results presented herein suggest that gold terminated branching silicon nanowires, could be strong candidates in building low power gas ionization sensors useful in highly selective detection of analytes with low adsorption energies. A simple case, i.e. detection of argon in nitrogen was demonstrated as a proof of concept.

7679-49, Session 10

N/MEMS: small components enable powerful microsystems

D. L. Polla, Defense Advanced Research Projects Agency (United States); M. B. Wolfson, System Planning Corp. (United States)

The last 15 years of MEMS technology has led to the creation of many diverse products driven by developments in manufacturing methodologies, new materials, and component integration strategies that have resulted in to versatile and powerful microsystems. Both commercial and defense products with MEMS Inside are just beginning to dramatically impact our lives.

In many areas of both physical and chemical microsystems, key principles of multi-domain scaling and heterogeneous integration of sub-components have represented successful strategies. N/MEMS, or Micro/Nanoelectromechanical Systems, include the integration of small sensors, actuators, electronics, photonics, energy, fluidics, chemistry, and biology into a meaningful system enabled by nanotechnologies, sub-micrometer structures, and engineering precision. This talk will describe some selected examples where opportunities for new enabling component capabilities and significantly enhanced performance over macroscale sensor approaches have been demonstrated.

Some general characteristics of N/MEMS technology demonstrated over the past decade have brought out six important themes: 1) MEMS and nanotechnology enable performance, 2) "smaller is better" is a consequence of multi-domain scaling; 3) simple is better, 4) MEMS technology commitment drives systems integration and innovation, 5) MEMS are reliable, and 6) a national MEMS basic research infrastructure is important to continued U.S. leadership. These valuable lessons have brought not only useful commercial and defense microsystems components, but are also showing the way to the beginning of the next small technological revolution in realizing powerful micro/nanosystems.

7679-50, Session 10

Nano thermotunneling systems for efficient power generation

M. Arik, J. W. Bray, S. E. Weaver, GE Global Research (United States)

Thermoelectrics have been investigated for their cooling and energy harvesting uses over the last six decades. Those devices can be bought from a number of commercial suppliers. Thermotunneling devices, on the other hand, have been known only for the last two decades, and nobody has been able to manufacture or show the performance of those devices. In this study, we will discuss the high thermodynamic efficiency of these systems and design bottlenecks to reach the high efficiencies such as thermal back path and electrical losses. Concepts for possible device designs will be discussed in detail. Efficiency of those devices will be compared with the conventional power generation as well as solid-state power generation systems. Thermodynamic limits of TT systems will be compared and first order economic analysis will be performed.

7679-51, Session 10

On-chip micropower

C. Wang, Florida International Univ. (United States)

Carbon microelectromechanical systems and carbon nanoelectromechanical systems (C-MEMS/NEMS) has received much attention because of their various potential applications, such as: Li-ion microbatteries, biofuel cells and supercapacitors. Electrostatic Spray Deposition (ESD) is another promising method to fabricate carbon based and metal oxide based porous structures which can be used as electrodes for micropower devices. In this talk, our recent progress in developing micropower based on various 3D carbon and hierarchical porous metal oxide electrodes will be presented.

7679-52, Session 10

Combining dissimilar materials at nanometer scale for energy harvesting

N. P. Kobayashi, Univ. of California, Santa Cruz (United States)

Development of next-generation energy resources that are reliable and economically/environmentally acceptable is a key to harnessing and providing the resources essential for the life of mankind. Our research focuses on the development of novel semiconductor platforms that would significantly benefit energy harvesting, in particular, from light and heat. In these critical application fields, traditional semiconductor solid-state devices, such as photovoltaic (PV) and thermoelectric (TE) devices based on a stack of single-crystal semiconductor thin films or single-crystal bulk semiconductor have several drawbacks, for instance; Scalability-limits when ultra-large-scale implementation is envisioned for PV devices and Performance-limits for TE devices in which the interplay of both electronic and phonon systems is important. In our research, various types of nanometer-scale semiconductor structures (e.g., nanowires and nanoparticles) coupled to or embedded within a micrometer-scale semiconductor structure (i.e., semiconductor nano-micrometer hybrid platforms) are explored to build a variety of non-conventional PV and TE devices. Two core projects are to develop semiconductor nano-micrometer hybrid platforms based on (1) semiconductor nanowires electrically connected to an array of micrometer-scale semiconductor pillars or thin films and (2) metallic

nanoparticles embedded within a micrometer-scale semiconductor thick film. The semiconductor nano-micrometer hybrid platforms are studied within the context of their basic electronic, optical, thermal properties, and their dependence on chemical interactions with environment, which will be further assessed and validated by comparison with theoretical approaches to draw comprehensive pictures of physicochemical properties of these semiconductor platforms.

7679-53, Session 10

Earth-abundant nano/micro-materials for enhanced photovoltaic and thermoelectric efficiencies

A. Boukai, Univ. of Michigan (United States)

Earth-abundant materials based on silicon are explored to enhance thermoelectric and photovoltaic efficiencies. Silicon nanomaterials are utilized to independently tune the electrical conductivity, Seebeck coefficient, and thermal conductivity to study heat transport at the nanoscale and to increase ZT. Nanostructuring of photovoltaic silicon cells is also utilized to increase the collection of minority carriers before recombination in metallurgical grade silicon.

7679-73, Poster Session

Optical fiber technology for sea monitoring and harbors protection

M. Pisco, M. Consales, Univ. degli Studi del Sannio (Italy); A. Iadicicco, S. Campopiano, Univ. degli Studi di Napoli Parthenope (Italy); S. Balzarini, OptoSmart s.r.l. (Italy); M. Sprovieri, S. Passaro, Consiglio Nazionale delle Ricerche (Italy); M. Giordano, Univ. degli Studi di Napoli Federico II (Italy); A. Cusano, A. Cutolo, Univ. degli Studi del Sannio (Italy)

In the recent years, our interdisciplinary research group have been engaged to address complementary and vertically integrated multidisciplinary goals of conceiving, studying and implementing advanced multi-parametric sensing technologies to be integrated within buoys, gliders, profilers infrastructure for estuaries, coastal areas and seas monitoring. The proposed technological platform would allow the on line monitoring of important physical and chemical parameters simultaneously to address environmental safety issues related to sustainable fishery activities, to assess the impact of climate change on key parameters for aquatic systems as defined by European policies and initiatives such as the Marine Thematic Strategy and the Maritime Policy Green Paper. In addition, the innovative choice of a single but advanced and high performances technology (optical fibers) would allow the implementation of sophisticate autonomous multifunction sensing systems ensuring unique advantages in terms of miniaturization, light weight, cost effectiveness, robustness and power consumption. In this framework, this new vision as well as preliminary results are presented.

7679-75, Poster Session

The Einstein relation in quantum wires of heavily doped nonlinear optical and opto-electronic materials: simplified theory and suggestion for experimental determination

S. Singharoy, JIS College of Engineering (India)

The influence of energy band models on the DMR in heavily doped nanostructured materials can be assessed from this work and the simplified analysis also covers various quantum confined compounds. Other types of quantum confined materials or other physical variables

have not been considered for plotting the DMR for the purpose of condensed presentation. The variations of the DMRs are totally band structure dependent. It is noted that in recent years, the mobilities of the nanostructures have been extensively studied, but the diffusion coefficients in such materials have been investigated to a lesser degree. The results of this paper can be used to determine the diffusion constants in various nanostructures by using the experimental values of the corresponding mobilities. Finally, it may be noted that the basic scheme of the present paper is not only to study the DMR but also to formulate the electron concentration, because the investigations of the different transport properties in nanostructures are based on the temperature dependent electron statistics in such materials with various dispersion laws.

7679-76, Poster Session

CVC and noise in hydrogen sensors

Z. O. Mkhitaryan, A. Durgaryan, V. M. Aroutiounian, V. M. Arakelyan, Yerevan State Univ. (Armenia)

The purpose of the work was the research of noise (at room temperature) and current-voltage characteristics (CVC) (in a range 20 - 90 0) of porous silicon (PS) under influence of H2

EXPERIMENT

The CVC and low-frequency noise spectra of samples up to, during time and on influence H2 are measured. Sensitivity of sensor traditional method on change of PS active resistance and noise method is determined. Results of researches are discussed.

CONCLUSIONS

- In samples with Au ohm contacts the height on the PS/SCS interface stays almost unchanged under H2 adsorption.

- At Pd rectifying contact to PS H2 adsorption reduce the height of the Schottky barrier on the Pd/PS interface, increasing currents through the structure.

- The increase of the low-frequency noise at H2 adsorption is connected with formation of donor type surface traps.

- After release of H2 in some samples partial relaxation of noise takes place (it is connected with process of chemical adsorption).

- At H2 adsorptions the noise spectra acquires a 1/f noise shape.

- For sensitivity estimation the noise method is more effective, than traditional method on change of PS active resistance.

- It has been shown that the sensitivity to H2 grows with temperature.

- The PS structures with Pd contact show higher sensitivity to H2 than the ones with Au contact.

7679-77, Poster Session

High-throughput readout system for cantilever-based sensing of explosive compounds

F. G. Bosco, Technical Univ. of Denmark (Denmark); E. Hwu, Academia Sinica (Taiwan); A. Boisen, Technical Univ. of Denmark (Denmark)

Cantilever based sensors are promising miniaturized sensing tools for bio-chemical applications. Small amounts of explosive can be detected by coating one side of the cantilever with molecules that bind explosive and thereby causes the cantilever to deflect. With these micro-mechanical sensors it is made possible to detect small amounts of explosives, both in air and liquid environment. This project focuses on the use of cantilever sensing for detection of trace particles of explosives like TNT, RDX and PETN, under the framework of the Xsense project. Normally the cantilever deflection is monitored by optical leverage. However these optical setup are typically big an bulky, making the in situ deployment of this technology very challenging. Here a novel approach of

measuring the absorption of analytes on the cantilever surfaces by using a lightweight, compact and high throughput optical device is presented. The optical readout of cantilever-based sensors has been re-designed and developed combining the technology of commercial DVD-ROM readers with a polymer based holding substrate structured with UV-lithography and imprint technology. Any kind of cantilever chip can be placed on the transparent holder, while the DVD-ROM reader is placed 1 mm below the substrate. The laser beam passes through the substrate and is focused on cantilevers with a 0.75 µm spot diameter. The reflected light is then recorded using an astigmatism-based 4-quadrant photodetector. The integration of the DVD reader with the on-substrate holding approach leads to a high throughput flexible platform, with easy auto-alignment and replacement of the cantilever chip. With this on-substrate approach tens of chips can be placed on the holder and read sequentially in a very compact device.

7679-78, Poster Session

Research of key technology in vibration measurement of small object

K. Yue, Xi'an Jiaotong Univ. (China); H. Huo, Xi'an Univ. of Science and Technology (China); F. Zhang, M. Zhang, Xi'an Jiaotong Univ. (China)

Research of vibration measurement of small objects has developed rapidly in recent years[1][2]. Especially with the development of Micro-electronic Mechanics System. Due to the small size of the MEMS, the traditional method of contact measurement seriously affects the parameter of the object measured. So a high accuracy non-contact measurement is required for optimization of micro-structure designs and improvement of its reliability[3][4]. We proved a laser time average interferometry to measure vibration of small objects. With optical amplification technology, the spatial resolution of the measurement has reach 5µm. The optical phase continuous scan technology is used to calibrate the optical phase-shifter. The anti-disturbance capability of this method is higher than that of the phase-stepping technique. The speckle average technology is used to eliminate the negative effect of measurement caused by background and speckle items. So the quality and signal-to-noise of interferogram are improved, which lead to better measurement result. This technology has the advantages of non-contact, high accuracy, full-field and fast speed. The resolution of the amplitude reaches 1nm in the experiments. The measurement system being full-field, the measuring speed of the measurement system can reach 512*512 points per half minute.

7679-79, Poster Session

Ordered nanoporous coatings for selective chemical detection

R. Houk, Sandia National Labs. (United States); J. Lee, Georgia Institute of Technology (United States); S. M. Thornberg, A. Robinson, J. A. Greathouse, M. D. Allendorf, Sandia National Labs. (United States); P. J. Hesketh, Georgia Institute of Technology (United States)

In this paper we demonstrate for the first time that novel nanoporous framework materials (NFM) such as metal-organic frameworks (MOFs) can be used to provide selectivity and sensitivity to a broad range of analytes including explosives, nerve agents, and volatile organic compounds (VOCs). NFM are highly ordered, crystalline materials with considerable synthetic flexibility resulting from the presence of both organic and inorganic components within their structure. Detection of chemical weapons of mass destruction (CWMD), explosives, toxic industrial chemicals (TICs), and volatile organic compounds (VOCs) using micro-electro-mechnical-systems (MEMS) devices, such as microcantilevers and surface acoustic wave sensors (SAWS), requires the use of recognition layers to impart selectivity. Traditional organic polymers are dense, impeding analyte uptake and slowing sensor

response. The nanoporosity and ultrahigh surface areas of NFM enhance transport into and out of the NFM layer, improving response times, and their ordered structure enables structural tuning to impart selectivity. Here we describe experiments and modeling aimed at creating NFM layers tailored to the detection of water vapor, explosives, CWMD, and volatile organic compound (VOCs), and their integration with the surfaces of MEMS devices. Molecular simulation shows that a high degree of chemical selectivity is feasible. For example, a suite of MOFs can select for strongly interacting organics (explosives, CWMD) vs. lighter volatile organics at trace concentrations. At higher gas pressures, the CWMD are deselected in favor of the volatile organics. We will also demonstrate the integration of various NFM on the surface of MEMS devices, and describe new synthetic methods developed to improve the quality of NFM coatings. Finally, MOF-coated MEMS devices show how temperature changes can be tuned to improve response times, selectivity, and sensitivity.

7679-80, Poster Session

Iron-manganese nanowires for magnetic sensing

J. M. Brown, C. G. Wilson, Louisiana Tech Univ. (United States)

The research presented in this abstract pertains to nanowire-structured magnetic sensors. The wires rely on giant magneto-resistance (GMR) in which an external magnetic field changes the electrical resistance of the nanowires significantly enough to detect very small changes in magnetic fields. The iron/manganese alternating bilayer nanowires presented here are fabricated by pulsed, template electrodeposition, a very simple and inexpensive process, especially compared to epitaxy and sputtering. System fabrication first involves anodizing a sheet of annealed aluminum in sulfuric acid to form a porous aluminum oxide layer on the surface. The pulsed power supply used for the nanowire fabrication consists of a square wave function generator, DC power supply, and an OPA541 op-amp wired in voltage follower configuration to change the function generator from a high-impedance source to a low-impedance source. The solution consisted of 50g/L iron(II) sulfate, 50g/L manganese(II) sulfate and 1% sulfuric acid. During the low cycle of the square wave (100mA/cm^2) only the iron will electrodeposit because the manganese requires a higher current density. During the high side of the square wave (300mA/cm^2) the iron and manganese will both deposit but the manganese deposits 30:1 more ions than iron at this current density leaving mostly manganese. The chemical make-up of the resulting 20nm diameter, 500nm length nanowires was 6 at% manganese and 45 at% iron, which is desirable because the ferromagnetic layer should be large in comparison with the non-magnetic layer (Mn). The resulting nanowires exhibited an 8% drop in resistance when exposed to an external magnetic field.

7679-81, Poster Session

Micro-calorimetric sensor for trace explosive particle detection

J. K. Olsen, A. Greve, Technical Univ. of Denmark (Denmark); L. R. Senesac, T. G. Thundat, Oak Ridge National Lab. (United States); A. Boisen, Technical Univ. of Denmark (Denmark)

Selectivity of gas sensors is normally achieved by immobilizing selective receptors on the sensor surface. These receptors will bind only to the desired target molecule, and the binding can be detected via for example mass changes, surface stress changes or by fluorescent labeling. However it is difficult to achieve reliable and reproducible data, and regeneration of the sensor surface in order to allow for new measurements is challenging. Using calorimetric sensing, a selective surface coating can be avoided and the surface is regenerated after each measurement.

Under the X-Sense framework program a micro calorimetric sensor has been developed aimed at detection of trace explosive particles. The

sensor is designed as a 400 µm x 100 µm x 200 nm silicon nitride bridge for thermal isolation, comprising 3 doped silicon resistors. Two resistors are used to heat the sensor above 800 °K using a controlled temperature ramp of 50 ms. The third resistor is used to monitor the temperature of the bridge.

A reference and a measurement chip are always used to obtain the differential signal. To compensate for difference in temperature response reference heating ramp is adjusted so both chips have the same temperature response. With closely matched temperature responses the differential signal can be amplified for increased sensitivity. Desorption or deflagration of material can then be monitored as a temperature change of the measurement chip.

Measurements of sub nanogram trace particles of TNT, RDX and PETN show unique desorption signature for each explosive giving both selectivity and sensitivity.

7679-82, Poster Session

Direct-write dispenser printed energy storage devices

C. C. Ho, J. W. Evans, P. K. Wright, Univ. of California, Berkeley (United States)

The miniaturization of autonomous electronic devices has precipitated a surge in engineering research towards developing permanent micropower supplies that can be integrated onto small, and often crowded device platforms. This has inspired research in a variety of fields including energy harvesting, power regulation, and energy storage. We have developed a simple, solutions-based processing method to incorporate zinc polymer microbatteries and activated carbon electrochemical capacitors directly onto a substrate with custom geometries. We use a direct write dispenser printer to deposit "inks" to form films, which when printed in a successive fashion, can be patterned into multilayer devices. The dispenser printer has precise lateral and vertical control between 5-500 µm. Because it is an additive process that deposits materials at room temperature and ambient conditions, the waste generated and process energy inputs are negligible, and it is an environmental tool in comparison to standard microfabrication processes. A combination of slurries and gels were developed to be compatible with this process but also have optimal functionality. For both devices, instead of traditional liquid electrolytes, ionic liquid gel electrolytes were optimized to have high mechanical strength but also good ionic transport properties. Slurry electrodes and current collectors were also developed. These materials have enabled the fabrication of fully printable, "solid-state" devices, eliminating the difficulties associated with processing and packaging liquid components. We have demonstrated the printing of microbatteries and supercapabitors, characterized their performance, and are part of a collaborative effort towards integrating these energy storage components onto functioning autonomous sensor prototypes.

7679-83, Poster Session

Nano-carbon-helixes

A. H. Jayatissa, The Univ. of Toledo (United States)

We have invented synthesis of carbon nanotubes at low temperature range of 600 degree C by a filament assisted chemical vapor deposition (CVD). This system could be used to synthesis carbon helix structures by changing the catalyst materials. The results indicated that synthesis of helix carbon structures with diameter from 20-500 nm range is possible with the current method. It has been reported that random deposition of carbon helix structured in CVD of carbon nanotubes. However, repeatability and reproducibility of early methods are unobvious for practical applications. We present the growth mechanism, controlling parameters, and some basic properties of these nano-carbon-helixes.

7679-85, Poster Session

Semiconductor materials characterization and identification with THz radiation

A. U. Sokolnikov, Visual Solutions and Applications (United States)

Recently evolved THz technology opens up more possibilities for identification and characterization of different semiconductor crystal-based compounds. Since the THz waveform is essentially a direct manifestation of the crystal domain structure, the multicycle THz generation methods allow measuring of geometrical parameters of semiconductor internal structures as well as of dislocations and other structural defects. The above is useful for both characterization and identification of the semiconductor materials. Further, methods of THz characterization of II-VI, III-V as well as of trinary compounds and thin films are discussed. The characterization of the latter has been hindered by the instability of the pump laser, which is very sensitive to slow fluctuations in temperature and humidity. Computational techniques are suggested allowing the noise level reduction for the above crystal structures measurements.

7679-86, Poster Session

In-situ catalytic monitoring on Pt-Vanadia nanosystems

C. T. Yavuz, Univ. of California, Santa Barbara (United States)

Most of the energy related chemical conversions take place with the help of a catalyst. Heterogeneous catalysts are widely used despite the lack of knowledge in the mechanism of activation. Surface X-ray diffraction techniques stand out among the tools to monitor crystal phases in situ while a catalytic reaction is taking place. They are advantageous over in situ transmission electron microscopy (TEM) and low energy electron diffraction (LEED) since they do not require low pressure environments or conductive samples. High intensity x-ray beams available at Synchrotron facilities (especially Grazing Incidence X-Ray Scattering - GISAXS) are highly precise on the incidental diffractions since it takes less (exposure) time to get data, thus, enabling real time monitoring. They also minimize the damage that comes from the x-ray beam since the contact time between sample and the beam is limited.

Methanol is considered as a hydrogen source for fuel cells and its chemical transformations are becoming increasingly important. Catalyst-methanol interaction could feasibly unravel some key characteristics of a good heterogeneous catalyst. Methanol oxidation by vanadium oxides is well studied, hence, serves as a good measure for catalytic activity. Highly ordered arrays of VO_2 nanowires grown on r-cut sapphire prove to be unique for the in situ catalytic activity tests. Here, we present size and morphology dependent activity of Platinum coated single crystalline VO_2 nanowires in methanol oxidation reactions. Our findings show an unexpected sintering behavior of Pt at temperatures as low as 200 oC.

7679-87, Poster Session

Modeling and in-situ observation of mechanical resonances in single, vertically oriented carbon nanofibers

L. C. Bagge, Jet Propulsion Lab. (United States) and The Univ. of Texas at Austin (United States); A. B. Kaul, Jet Propulsion Lab. (United States) and California Institute of Technology (United States)

Carbon nanotube (CNT) mechanical resonators were explored for their potential use in high-frequency, high-Q, miniaturized resonators for communications and sensing applications. The nano-electro-mechanical (NEMs) resonators were modeled using a commercially available finite-element-simulator. Boundary conditions of a DC model were modified to examine the electro-mechanical coupling of the CNT to an incoming

AC signal delivered by a probe in close proximity to an individual tube. The modeling results confirmed that the mechanical resonance was maximized when the frequency of the input signal was equal to the first order harmonic of the CNT. A parametric investigation of the resonance frequency was also performed for various geometrical parameters for our architecture. Finally, we also report on the in-situ observations of mechanical resonance in single, vertically oriented tubes, where such measurements were conducted inside an SEM. This work confirms the suitability of our vertically oriented tubes for resonator applications, such as filter banks in communication systems or mass sensing applications.

7679-88, Poster Session

An explicit formula for determination of simulation runs for analysis of nano-VLSI circuits

X. Chen, Southern Univ. (United States)

In this article, we derive an explicit formula for determining the appropriate number of simulation runs for estimating the parametric yield or violation probability of VLSI circuits. The formula involves no approximation and thus offers a rigorous control of the statistical error of estimation. Moreover, the formula is substantially less conservative than existing methods and hence can be used to avoid unnecessary computation.

The formula can be of particular importance in investigating the impact of parametric variation for VLSI circuits and other type of devices, especially when the geometries of the circuits or devices are in the nano scale.

7679-89, Poster Session

Nanostructure-based antireflection coatings for EO/IR sensor applications

A. K. Sood, R. E. Welser, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); E. F. Schubert, M. F. Schubert, Rensselaer Polytechnic Institute (United States); D. L. Polla, Defense Advanced Research Projects Agency (United States); M. B. Soprano, U.S. Army Research Development and Engineering Command (United States)

EO/IR Nanosensors are being developed for a variety of Defense and Commercial Systems Applications. These include UV, Visible, NIR, MWIR and LWIR Nanotechnology based Sensors. The conventional SWIR Sensors use InGaAs based IR Focal Plane Array (FPA) that operate in 1.0-1.8 micron region. Similarly, MWIR Sensors use InSb or HgCdTe based FPA that is sensitive in 3-5 micron region. More recently, there is effort underway to evaluate low cost SiGe visible and near infrared band that covers from 0.4 to 1.6 micron.

One of the critical technologies that will enhance the EO/IR sensor performance is the development of high quality nanostructure based antireflection coating. Prof. Fred Schubert and his group have used the TiO2 and SiO2 graded-index nanowires / nanorods deposited by oblique-angle deposition, and, for the first time, demonstrated their potential for antireflection coatings by virtually eliminating Fresnel reflection from an AlN-air interface over the UV band. This was achieved by controlling the refractive index of the TiO2 and SiO2 nanorod layers, down to a minimum value of n = 1.05, the lowest value so far reported .

In this paper, we will discuss our modeling approach and experimental results for using oblique angle nanowires growth technique for extending the application for UV, Visible and NIR sensors and their utility for longer wavelength application.

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7679-90, Poster Session

Pulsed digital oscillators as a tool for the selective activation of MEMS resonant modes

M. Dominguez-Pumar, Univ. Politècnica de Catalunya (Spain); E. Blokhina, Univ. College Dublin (Ireland); J. Pons-Nin, J. Ricart, Univ. Politècnica de Catalunya (Spain); O. Feely, Univ. College Dublin (Ireland); J. L. Sánchez-Rojas, Univ. de Castilla-La Mancha (Spain)

The objective of this paper is to show that Pulsed Digital Oscillators, PDOs, may be used to selectively activate certain resonant modes of MEMS structures simply by changing some parameters of the oscillator. PDOs are sampled circuits that generate pulsed actuations to obtain self-sustained oscillations on MEMS resonators near their resonant frequency. The sign of the position samples of the resonator is filtered with a feedback filter and fed into the resonator. This same bitstream is the output of the oscillator, and from there the output frequency can be easily recovered. The sampling frequency may be above or below the Nyquist limit, on which case small changes in the resonant frequency can be easily monitored.

PDOs may be configured either to generate self-sustained oscillations on MEMS resonators, or generate pulsed excitations to extract the energy stored in the resonator. The spectrum is divided in 'frequency bands' where the oscillation and anti-oscillation behaviour is alternated. By choosing a feedback filter and a sampling frequency, it is possible to locate any resonant frequency related to a resonant mode in a oscillation band, while keeping the others in anti-oscillation bands. With this procedure, it is possible to select which resonant mode is activated.

Extensive experimental results have been obtained. The excitation of different resonant modes of a MEMS cantilever is measured with a scanning Doppler vibrometer.

7679-91, Poster Session

Sn nanoparticles encapsulated in hollow carbon nanofibers as an anode electrode for Li-ion battery application

C. Wang, Florida International Univ. (United States); Y. Yu, J. Maier, Max-Planck-Institut für Festkörperforschung (Germany)

The development of high-performance electrode materials is in urgent need for new generation Li-ion batteries with high energy density and power density. Currently, graphite is commercial available anode material since 1990. However, its theoretical capacity is much lower compared to other materials, such as Sn. However, the practical implementation of these tin-based composites is hampered by the large capacity loss of first cycle and poor cyclability. One reason for the capacity loss is attributed to the significant volume changes that occur during charging and discharging, which causes mechanical failure and the loss of electrical contact at the electrode. Another reason is the aggregation of tin nanoparticles formed during the process of discharging of Sn-Li alloy. Several approaches have been proposed to increase electrochemical performance of Sn anode by using modified electrode configuration, decreased the particle size, and optimized binder. Recently, the most relevant results have been obtained by preparing nanostructured tin particles dispersed in a carbon matrix and carbon-encapsulated hollow tin nanoparticles. In this work, we report a simple and flexible coaxial electrospinning method to fabricate tin nanoparticles encapsulated in hollow carbon nanofibers. This Sn@C composite anode material was demonstrated as a very promising anode material for Li-ion battery application.

7679-92, Poster Session

Dielectric charging control for electrostatic MEMS switches

M. Dominguez-Pumar, D. López, D. Molinero Giles, J. Pons-Nin, Univ. Politècnica de Catalunya (Spain)

The aim of this paper is to introduce a new method to dynamically control the amount of parasitic charge injected in dielectric layers of electrostatic MEMS switches. This method is based on voltage polarity switching and it can be used to significantly increase lifetime and reliability of electrostatically actuated MEMS devices, thus extending their potential use to a wider range of applications. The method is based on the opposite behavior exhibited by the dielectric charging phenomena when volatge stresses of different sign are applied to a given device. To this effect, a low-pass sigma-delta modulation scheme was implemented through the following algorithm: the input capacitance of the MEMS device is periodically sampled and, according to the comparison of the sampled capacitance with a reference, or target, value, positive or negative actuation voltages are supplied in the next sampling period. An experimental setup, which includes an LCR precision meter controlled from a PC and a parallel-plate MEMS switch, was built to implement and test the control method. Experimental results obtained with this setup show that the device capacitance (and thus the MEMS position and the charge trapped in the dielectric) can be kept closer to the target value for long periods of time, without noticeable changes on device performance or reliability. The spectrum of the bit stream extracted from the actuation pulses is very similar to those obtained in sigma-delta sensing applications. Thus the feasibility and potentialites of the method proposed are experimentally demonstrated.

7679-93, Poster Session

Metal-insulator-metal tunneling diode for uncooled infrared high-speed detectors

I. Wu, Nano CVD Co. (United States) and Univ. of South Florida (United States); N. Kislov, Nano CVD Co. (United States); J. Wang, Univ. of South Florida (United States)

A metal-insulator-metal tunneling diode (MIMTD) having response times less than 10e-12 seconds is extremely important for uncooled detectors operating at terahertz/infrared frequencies. We are looking for the technology for fabrication of nanogap MIMTDs having junction area in the range of 10e-14m2, thus enabling the coveted terahertz frequencies due to the greatly reduced junction capacitance. A contemporary electron beam stepper of such resolution costs tens of millions and is viable for mass production. This work employs standard photolithography and atomic layer deposition (ALD) methods, which allow formation of a micrometer-wide stripe in the second metal layer separated from the end of the metal stripe in the first layer by an ALD-deposited sidewall dielectric spacer, thus forming a nm-thick vertical tunneling junction. The junction area is defined by the width and thickness of the stripe, while the junction thickness is controlled by the ALD process. So far, by using a newly developed process, MIMTD with micron-scale self-aligned cross-fingers have been successfully demonstrated. Through this process, we have investigated a wide variety of metal and insulator materials such as Au, Pt, Ni, Al, Al2O3, and HfO2 to advance the performance of the MIMTD. Some preliminary characterization of I-V and C-V characteristics of the fabricated MIMTD structures has been carried out. Ongoing research for modeling of MIM tunneling diode based on measured data and further reduction of the device junction area enabled by the new process will lead to the MIM that could appreciate the infrared and terahertz spectra.

7679-94, Poster Session

Multifunctional nanodevices for energy harvesting in unconventional spectral ranges

O. Imafidon, S. Georgakopoulos, N. Pala, Florida International Univ. (United States)

New energy harvesting technologies have drawn interest in recent years for both military and commercial applications. We present complete analysis of a novel device technology based on nanowire based antenna and very high speed rectifiers (collectively called nanorectenna) to convert infrared and THz electromagnetic radiation into DC power.

A nanowire antenna can receive electromagnetic waves and an integrated rectifier can convert them into electrical energy. The induced voltage and current distributions of nanowire antennas for different geometric parameters at various frequencies are investigated and analyzed. Also, nanowire antenna arrays with different geometries and distributions are examined. The efficiency of nanowire antennas and its polarization dependency are extensively studied. Moreover, novel nano-antennas are proposed for broadband operation and power conversion. All numerical computations are conducted using Ansoft HFSS. An incident plane wave was used to excite the nano-antennas and simulations were carried out for frequencies between 0.1THz and 100 THz. The induced voltage on the nano-antennas is measured on the thin oxide layer. Finally, optimum geometries of nanowires are proposed in order to maximize the amount of infrared power that is harvested.

7679-95, Poster Session

Silicon nanowires for multisensing application

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Since almost a decade, silicon nanowires have been intensively evaluated for detecting chemical and biological species without labeling. Detection levels at the state of the art have been demonstrated for DNA, proteins and viruses species. The potential of this technology is enormous for defense and environment applications where integration, rapidity and simplicity of an analysis are key factors. Nevertheless, several questions remain open:

- the ability to produce and interface these nanosensors at the industrial scale,

- the possibility to apply this technology in a "real-life" environment, where a lot of parameters could influence the sensing device.

To address the first question, we developed in a microelectronic clean room a top-down fabrication process of silicon nanowire field effect transistors on 200 mm SOI wafers. 80 chips per wafer, each chip integrating several hundreds of nanosensors, were produced. The dimensions of the sensors are typically few microns length and few tens of nanometers height and width.

To evaluate the ability of these nanowires to act as reliable sensors in a complex environment, we characterized and quantified their response to several parameters: light, temperature, humidity, electrostatic environment, flow rate, concentration of salts, pH.

We especially demonstrated a high sensitivity to the salt concentration (down to 10-7 M) and to the flow rate (= 0.7 µL/min), 5 times better that recently published results. Knowing the influence of all these parameters, an extended study on DNA sensing is under progress.

7679-96, Poster Session

Fabrication of freestanding SWCNT networks for fast microbolometric focal plane array sensor

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We have investigated the feasibility of significantly improving the performance of currently favored uncooled infrared (IR) detectors based on Si or VOx microbolometers with a new design employing freestanding suspended network of single-walled carbon nanotubes. Such networks would have high absorption coefficient, high temperature coefficient of the resistance (TCR) and extremely low thermal mass. This combination of parameters would translate into an uncooled IR detector with high sensitivity and a short time constant , or very fast temporal response. We demonstrate a method to prepare such suspended networks by selective removal of a sacrificial oxide layer forming a cavity under the CNT network.

Suspended SWCNT ribbons exhibit extremely large bolometric response [1] over a wide temperature range,Suspended SWCNT ribbons exhibit extremely large bolometric response [1] over a wide temperature range, including room temperature. Thus, SWCNT network is an ideal candidate for developing a low cost uncooled IR detector. Recently, devices based on individual tubes have shown promising results [2] not only in photodetection but also in multiple sensor applications [3] (e.g. chemical, biological agents). However, they are extremely difficult to mass-produce reliably, because each individual nanotube is different. Scaled-up production of such devices may be impossible. We approach Figure 1. Schematic drawing of fabrication steps (above) and SEM micrograph of sparse SWCNT network (below left), SEM micrograph of freestanding network across gold contacts (below right). this problem by employing uniform, sparse network of SWCNT, which is grown by CVD or deposited from solution and then electrically contacted, characterized and under-etched to form active suspended region with bolometric response. We compare under-etching by vapor phase HF and by aqueous buffered HF followed by critical point drying to prevent destruction of fine suspended structure by interfacial forces during drying. Statistical response of SWCNT network should be comparable to that of individual tubes that exhibit very high absorption coefficient [4], and will be more consistent, predictable and reliable. There is no major obstacle to the production of very large array of such active devices (pixels) in a single fabrication step and producing a focal plane array (FPA). Such FPAs should be able to operate at room temperature with comparable or better sensitivity than the current vanadium oxide based FPAs, and with time constant substantially lower than that for regular microbolometers; we conservatively expect frame rates in excess of 1kHz with SWCNT bolometers. This order of magnitude improvement in frame rate would greatly expand the application domain of the proposed bolometers to image fast changing scenes, thereby improving considerably the situational awareness.

7679-97, Poster Session

Experimental demonstration of lossy recording of information into DNA

M. E. Slowe, Duke Univ. (United States); E. Vasievich, The Univ. of North Carolina at Chapel Hill (United States); J. Protz, Duke Univ. (United States)

The concept of "genetic memory" is demonstrated through the recording of the time-history of state variables. We hypothesized that information could be stored into non-coding DNA using thermosensitive liposomes as sensors and measuring transport state variable information through DNA release and binding in response to stimuli. To test our hypothesis, we performed experiments that demonstrated in situ de novo synthesis of information-encoding DNA using natural biomaterials. Our results were compared to a lumped-parameter model designed to simulate the experiments. We found excellent correlation between the DNA sequences generated by the simulations and those generated experimentally, suggesting that the in situ, de novo -synthesized DNA does store recoverable information by the mechanism proposed.

7679-98, Poster Session

Microscale ethanol vapor ejector and injector

W. G. Gardner, J. W. Jaworski, I. Wang, N. A. Brikner, J. Protz, Duke Univ. (United States)

Two non rotating pumping components, a jet ejector and injector, were designed and tested. A microscale ethanol vapor driven jet ejector was designed and tested to induce a suction draft using a supersonic micronozzle. Three-dimensional axisymmetric nozzles were fabricated using electro-discharge machining to produce throat diameters of 90mµ, 187 mµ and 719 mµ with expansion ratios of 3:1. The motive nozzles achieved design mass flow efficiencies above 90% compared to isentropic calculations. Two motive fluids, ethanol vapor and nitrogen gas, were used separately to motivate and entrain ambient air. Experimental data indicate that the ejector can produce a sufficient suction draft to satisfy both microengine mass flow and power off-take requirements to enable its substitution for high speed microscale pumping turbomachinery. An ethanol vapor driven injector component was designed and tested to pressurize feed liquid ethanol. The injector was supplied with 1.70 atmosphere ethanol vapor and pumped liquid ethanol up to a total pressure of 3.02 atmospheres. Dynamic pressure at the exit of the injector was computed by measuring the displacement of a flat plate placed over the outlet stream. The injector employed a three-dimensional axisymmetric nozzle with a throat diameter of 719 mµ and a three-dimensional converging axisymmetric nozzle. The experimental data indicate that the injector can pump feed liquid into a pressurized boiler, enabling small scale liquid pumping without any moving parts. Microscale injectors could enable microscale engines and rockets to satisfy pumping and feedheating requirements without high speed microscale turbomachinery.

7679-54, Session 11

Silicon carbide NEMS logic for high-temperature applications

M. Mehregany, T. Lee, Case Western Reserve Univ. (United States)

Nano-electro-mechanical systems (NEMS) switches are of interest for hybridization with transistors in electronic logic circuits and for realization of all-mechanical logic circuits. Being mechanical, they essentially have zero leakage current in OFF state. While continued miniaturization has led to increased transistor leakage current in conventional silicon circuits, our interest is in high temperature silicon carbide (SiC) circuits, where transistor leakage current increases expeditiously with temperature. Henceforth, we are developing NEMS SiC switches capable of operation from 25°C to 600°C, with threshold voltages ≤5 V, consistent with the threshold voltages of our SiC transistors. Our SiC switches, actuated electrostatically, have a cantilever-type architecture wherein one electrode is pulled down to contact the other. The switches, fabricated using surface micromachining, have electrode separation gaps determined by the ~75 nm-thick sacrificial SiO2.

Two-terminal switches have been cycled more than 40 billion times at room temperature until failure and more than 2 million times at 600°C when the package wire bonds fail. Plausible models for the observed contact resistances are: (i) native oxide on the SiC electrodes for low actuation voltages; and (ii) Sharvin's model for higher actuation voltages.

Stiction of the switch electrodes during fabrication and in operation is strongly correlated to the roughness of the contacting surfaces. 60% of switches with 8 nm roughness could be cycled over billions of times, at which point the cantilever electrodes fracture at their support ends. In contrast, 85% of the switches with 1 nm roughness were stuck after

release.

7679-55, Session 11

Science and technology of ultrananocrystalline diamond thin films applied to monolithically integrated RF MEMS-NEMS/CMOS devices for high-performance RF systems

O. Auciello, A. V. Sumant, Argonne National Lab. (United States); C. Goldsmith, MEMtronics Corp. (United States); C. Gudeman, Innovative Micro Technology (United States); J. Carlisle, Advanced Diamond Technologies, Inc. (United States); V. P. Adiga, R. W. Carpick, Univ. of Pennsylvania (United States); D. C. Mancini, Argonne National Lab. (United States)

A new generation of RF MEMS/NEMS devices will require advanced materials development and integration, and new processing techniques to achieve high device performance. However, long term reliability and durability are still main areas of concern for many MEMS/NEMS devices based on Si, due its poor mechanical, tribological , and surface properties, which limits the devices performance in several applications. Of particular interest to this talk are MEMS/NEMS resonators, RF switches, and other devices involving sliding or contacting interfaces. A unique material developed in thin film form at Argonne National Laboratory and named ultra-nanocrystalline diamond (UNCD), due to its nanostructure with 2-5 nm grain dimensions, exhibits exceptional mechanical and tribological properties suited for the development of a new generation of high-performance MEMS/NEMS devices, such as resonators and RF switches specifically. UNCD exhibits extremely high Young modulus (~ 980), and high sound propagation velocity (16000 m/sec), comparable to single crystal diamond, and far superior to Si and other alternative MEMS materials. Thus UNCD enables the fabrication of very high Q resonators for the high GHz frequency range. On the other hand, our team has recently demonstrated that controlled incorporation of hydrogen into the grain boundaries of UNCD film results in control of electrical charging and discharging speed, enabling the use of UNCD as a dielectric layer in RF MEMS switches with practically no failure due to electrical charging, thus, practically eliminating the prevalent failure in RF MEMS switches using conventional oxide or nitride dielectric layers. We will review the work done by our team on the development of UNCD-based resonators and RF switches under a DARPA funded program, and a brief view to UNCD-based NEMS devices.

7679-56, Session 11

Piezoelectric AlN MEMS/NEMS resonators and switches

G. Piazza, Univ. of Pennsylvania (United States)

A major challenge associated with the demonstration of high frequency MEMS/NEMS components is the ability to efficiently transduce the mechanical device. This work presents noteworthy opportunities associated with the scaling of piezoelectric AlN films from the micro to the nano realm and their application to the making of efficient NEMS resonators and switches that can be directly interfaced with conventional electronics.

Experimental data showing NEMS AlN resonators (250 nm thick with lateral features as small as 300 nm) vibrating at record-high frequencies approaching 10 GHz with Qs in excess of 500 will be presented. The extreme compact form factor of these devices permits to envision large scale integration (LSI) of NEMS to develop disruptive microwave architectures. Similarly, these NEMS resonators can yield unprecedented

sensitivities and be employed to tag analyte concentrations that reach the part per trillion levels. Preliminary results on the use of NEMS resonators for gas sensing will be used to highlight the key advantages of the piezoelectric nano-transducer technology and how scaling to the nano-realm can be advantageously harnessed to simultaneously achieve large dynamic ranges and extreme resolution.

The use of nano-piezoelectric films (100 nm thick) for NEMS actuators for switching applications will be shown and experimental data confirming that bimorph nano-piezo-actuators can have the same piezoelectric properties of microscale counterparts will be presented. These actuators set a realistic pathway towards the demonstration of nanomechanical computing elements.

Challenges associated with the miniaturization of MEMS devices, especially in regards to fabrication and dimensional tolerances will also be discussed.

7679-57, Session 11

Fabrication and characterization of ultrananocrystalline diamond nanowires for developing next-generation of nano-electronic and NEMS devices

A. V. Sumant, V. Joshi, L. E. Ocola, D. Lopez, B. Kabius, O. Auciello, D. C. Mancini, Argonne National Lab. (United States); X. Wang, Univ. of Puerto Rico (United States)

Currently, there is tremendous interest in fabricating diamond nanowires (DNWs) and diamond nano-rods (DNRs) due to their extraordinary mechanical, electrical, and optical properties as predicated by theory for quasi 1-dimensional sp3 nanostructures. Synthesizing or fabricating these nanostructures is proving to be very challenging. To date, only a few attempts have been reported, either by etching single crystal diamond lithographically to produce DNRs or by coating Si nanowires with nanocrystalline diamond to produce DNRWs. We report a method based on e-beam lithography and reactive ion etching of ultrananocrystalline diamond (UNCD), to produce UNCD DNWs with nanowire diameter in the range of 20-200 nm. Since they are produced by a lithographic approach, they can be fabricated with a well defined position and nanometer scale precision. We have fabricated nitrogen-doped (N-UNCD) DNWs and characterized them using UV-visible Raman spectroscopy, and transmission electron microscopy (TEM) including electron energy loss spectroscopy (EELS) to analyze their nanostructure, bonding configuration and surface chemistry. We will discuss preliminary characterization studies of N-UNCD DNWs and measurements of their electrical properties. The ability to fabricate N-UNCD DNWs provides an opportunity to study the fundamental mechanism of electrical transport processes in DNWs, which will enable new ideas and possibilities for the fabrication of nanoelectronic devices and nanoelectromechanical (NEMS) sensors with increased sensitivity and new functionalities for a variety of applications.

7679-58, Session 11

Characterization of nitrogen-doped ultrananocrystalline diamond as a robust cold cathode material

S. A. Getty, NASA Goddard Space Flight Ctr. (United States); O. Auciello, A. V. Sumant, Argonne National Lab. (United States); D. P. Glavin, P. R. Mahaffy, NASA Goddard Space Flight Ctr. (United States)

Carbon materials, including carbon nanotubes and nanostructured diamond, have been of considerable interest for field emission

applications for over a decade. In particular, robust field emission materials are compelling for space applications due to the low power consumption and potential for miniaturization. A miniaturized mass spectrometer under development for in situ measurements on the moon and other Solar System destinations is planned to use a field emitter to generate ions from gaseous samples using electron impact ionization. For these unusual environments, robustness, reliability, and long life are of paramount importance, and to this end, we have explored the field emission properties and lifetime of carbon nanotubes and nitrogen-doped ultrananocrystalline diamond (N-UNCD) thin films (the latter developed and patented by Argonne National Laboratory). We will present recent results revealing that N-UNCD, with threshold field as low as 3-5 V/μm, offers stable performance in the μA range of emission current in high vacuum for up to 1000 hours.

7679-59, Session 11

Science and technology of MEMS/NEMS resonators: Si versus diamond platform materials

J. Wang, Univ. of South Florida (United States)

Having recently been demonstrated at frequencies over 1GHz with measured Q's>10,000, MEMS/NEMS resonators have great potential for enabling on-chip high-Q passives needed in wireless communication systems for frequency generation, translation and filtering. However, the acceptance of such devices for RF applications in present-day transceivers has been hindered so far by several remaining issues, including: (1) a frequency range lower than 5 GHz, (2) higher impedances than normally exhibited by macroscopic high-Q resonators, (3) limited linearity and power handling ability, and (4) insufficient frequency repeatability and stability.

This paper reviews several material-centric strategies for alleviating the aforementioned issues. Given that resonance frequency is generally proportional to the acoustic velocity while energy dissipation and Q is also a strong function of the material properties, several device-oriented and system-level performance-enhancing technologies will be evaluated. Particularly, a systematic investigation of MEMS/NEMS resonators fabricated in amorphous, polycrystalline and crystalline silicon along as chemical vapor deposited diamond with the highest acoustic velocity among thin-film depositable materials will be conducted. The resonator equipped with capacitive or piezoelectric transducers behaves as an electrical device when looking into its ports. Both capacitively and piezoelectrically-transduced resonators will be discussed with a particular emphasis on the employment of transducers with improved electromechanical coupling coefficient as the major device-level approach for lowering impedance. Finally, the advent of mechanically-coupled arraying as a system-oriented approach enables the composite resonators to obtain unprecedented performance such as reduced motional impedance, improved frequency repeatability and stability, as well as enhanced linearity and power handing capability.

7679-60, Session 12

Pixelated hyperspectral filter for integrated focal plane array in the long-wave IR

S. A. Kemme, R. R. Boye, A. A. Cruz-Cabrera, R. D. Briggs, T. R. Carter, S. Samora, Sandia National Labs. (United States)

We present design, fabrication, and characterization for a pixelated, multispectral arrayed component for Focal Plane Array (FPA) integration in the Long-wave IR (LWIR). This component contains tens of pixels in a single super-pixel and that super-pixel is tiled across the full extent of the FPA. Each spectral pixel is to map to a single FPA pixel with a spectral FWHM; approximately 100nm. With this arrayed approach, remote sensing data may be accumulated with a non-scanning, "snapshot" imaging system.

This technology must be flexible in individual pixel center wavelength and pixel position within the array. Moreover, the entire pixel has a single wavelength response, not the integrated linear response of a graded cavity thickness design. These requirements bar tilted, linear array technologies where the cavity length monotonically increases across the device.

Fabrication challenges are apparent with traditional, thin-films, serial approaches where each filter pixel is layered in isolation while neighboring filter pixels are masked. Compounded misalignments and rounded topologies would significantly reduce the clear aperture of each pixel and drastically impact successful fabrication yield. We are avoiding these problems by pursuing designs that determine a pixel's spectral response through a wafer-level deposition and a unique lithographically-applied lateral feature. Finally, we consider the diffraction effects in the design and layout of this pixelated filter component where pixel dimensions are only a few wavelengths.

7679-61, Session 12

Design and development of carbon nanostructure-based microbolometers for IR imagers and sensors

A. K. Sood, R. A. Richwine, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); G. E. Fernandes, J. Xu, Brown Univ. (United States); N. Goldsman, Univ. of Maryland, College Park (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States); B. Lineberry, U.S. Army (United States)

EO/IR Sensors and imagers using nanostructure based materials are being developed for a variety of Defense Applications. In this paper, we will discuss recent modeling effort and the experimental work under way for development of next generation carbon nanostructure based infrared detectors and arrays. We will discuss detector concepts that will provide next generation high performance, high frame rate, and uncooled nano-bolometer for MWIR and LWIR bands. The critical technologies being developed include carbon nanostructure growth, characterization, optical and electronic properties that show the feasibility for IR detection. Experimental results on CNT nanostructures will be presented. We will discuss the path forward to demonstrate enhanced IR sensitivity and larger arrays.

7679-62, Session 12

Opto-acoustic antennas for ocean sensing and monitoring: perspective and challenges

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We report on the recent results obtained with a new opto-acoustic antenna realized with fiber optic technology. The fiber optic antenna is constituted by a FBG (Fiber Bragg Grating) coated with a proper polymeric material. The polymeric coating has the function to improve the coupling with the incident sound wave and to transfer the deformation to the FBG which in turn undergoes dynamically a Bragg wavelength shift

under the influence of the sound pressure.

In order to control the behavior of the hydrophone in terms of sensitivity and bandwidth, a numerical analysis has been performed to study the influence of the physical and geometrical features of the coating on the performances of the opto-acoustic antenna.

On the basis of the numerical analysis, FBGs coatings have been realized with proper materials, characterized by different elastic modulus (much lower than that of the fiber) and shapes (cylindrical and spherical) in order to obtain opto-acoustic antennas with difference features.

An experimental analysis has been carried out in a sensing tank to characterize the antennas performance in-field. In comparison with conventional fiber optic hydrophones based on bare FBGs, an increase of sensitivity is obtained with excellent performances in terms of linear response and wide dynamic range. Thanks to the simplicity of its operating principle, geometry and interrogation scheme, these opto-acoustic antennas can provide an alternative to the current state of the art in piezoelectric hydrophone technology.

7679-63, Session 13

Micro- and nano-technology for Navy and Marine Corps EO/IR sensors and sensor systems

M. Duncan, Office of Naval Research (United States)

Micro- and nano-technology is finding an ever-increasing number of applications in sensors and sensor systems for the Department of Defense. In particular, the use of this technology enables lighter, smaller, and more highly capable sensor payloads for use by the Navy and Marine Corps. The Office of Naval Research is particularly interested in developing agile, highly capable multi-sensor payloads for use in small unmanned aerial systems. Micro- and nano-technology can help to enable such payloads as well as to perform unique functions in the sensors themselves. I will describe how the Office of Naval Research works to develop such technology in a general way, and then describe more specific examples of how micro- and nano-technology, such as micro-mirror arrays and related technology, is being used for ongoing EO/IR sensor programs. I will also describe general future needs for EO/IR sensors and sensor systems and discuss how micro- and nano-technology might play a role to address those needs.

7679-64, Session 13

Titanium dioxide waveguide with an embedded grating coupler

E. Gillman, A. Raspopin, D. J. Costello, M. Moreno, Senspex, Inc. (United States); R. Kasica, National Institute of Standards and Technology (United States)

Optical transport in planar waveguide structures is of great importance for spectroscopic chemical and biological sensing applications. We have fabricated a TiO2-polymer planar waveguide with an embedded grating coupler. The grating coupler consists of a low index layer of SiO2 on a Si(100) substrate. The SiO2 layer has a grating pattern reactive ion etched into the surface. On top of this surface is a high index TiO2 waveguide. The TiO2 film is generated from a spin-coated polymer solution, OptiNDEX EXP04054 from Brewer Science. The TiO2 film has low optical absorption, a high refractive index, and good thermal and UV stability. It is possible to make up to a 420nm film in a single coating operation. To form the TiO2 film the polymer solution is spin-coated onto a wafer and the wafer is baked at 300 C for 10 minutes. Scanning electron microscopy and focused ion beam cross sections verified that the TiO2 conformally fills the groves of the grating. We made electrodynamic calculations based on the indices of the materials for our waveguiding structure and the wavelength of the incident light for single-mode wave guiding. These calculations gave a projected TiO2 thickness for our waveguides. Experimental results show that the

waveguide structures that we fabricated were in close agreement with these predictions.

7679-65, Session 13

A MEMS-based, wireless, biometric-like security system

J. Cross, J. Schneiter, Veratag, LLC (United States); G. C. Leiby, S. McCarter, J. Smith, T. Budka, RF Diagnostics, LLC (United States)

We present a system for secure identification and authentication applications that is based upon biometric-like MEMS chips. The MEMS chips have unique, complex frequency signatures that are the result of random fabrication process variations. In this sense, the MEMS chips possess something analogous to a distinct vocal pattern, or "voiceprint". The MEMS chips are vacuum encapsulated, rugged, and suitable for low-cost, high-volume mass production. Furthermore, the MEMS chip fabrication process is fully integrated with standard CMOS fabrication methods.

One is able to operate the MEMS-based security system in much the same way that a conventional RFID system is operated: the reader (essentially a custom built, low-cost network analyzer) detects the power reflected across a frequency spectrum from a MEMS chip in its vicinity. We demonstrate prototype "tags" - MEMS chips placed on a credit card-like substrate - to show how the system could be used in standard identification or authentication applications. We have integrated power scavenging to provide DC bias for the MEMS chips through the use of a 915 MHz source in the reader and a RF-DC conversion circuit on the MEMS tag.

The system enables a high level of protection against typical RFID cloning and spoofing attacks. There is no need for signal encryption, so back-end infrastructure is minimal. Overall, we believe this system would make a viable low-cost, high-security system for a variety of identification and authentication applications.

7679-66, Session 13

New quantum dot sensors

Y. K. Gun'ko, Trinity College Dublin (Ireland)

Quantum dots (QDs) are fluorescent semiconductor (e.g. II-VI) nanocrystals, which have a strong characteristic spectral emission. This emission is tunable to a desired energy by selecting variable particle size, size distribution and composition of the nanocrystals. QDs have recently attracted enormous interest due to their unique photophysical properties and range of potential applications in photonics and biochemistry. The main aim of our work is develop new materials based chiral quantum dots (QDs) and establish fundamental principles influencing their structure, properties and biosensing behaviour. Here we present the synthesis and characterisation of various chiral II-VI (CdS, CdSe and CdTe) semiconductor nanoparticles and utilisation as new chiral biosensors. Penicillamine stabilised CdS and CdSe nanoparticles, which have shown both very strong and very broad luminescence spectra. Circular dichroism (CD) spectroscopy studies have revealed that the D- and L- penicillamine stabilised CdS and CdSe QDs demonstrate circular dichroism and possess almost identical mirror images of CD signals. Studies of photoluminescence and CD spectra have shown that there is a clear relationship between defect emission and CD activity. We have also demonstrated that these new QDs can serve as fluorescent nanosensors for various chiral biomolecules including aminoacids and nucleic acids. These novel nanosensors can be potentially utilized for a single molecule detection of various biological and chemical species with the applications in forensic science, anti-terrorism and defense sectors.

7679-67, Session 14

Integrated nanophotonics and unconventional optics

R. Hammond, U.S. Army Research Office (United States)

The Army of the 21st century will rely more on sensing, imaging processing, and autonomous target tracking and recognition than ever before. My program investigates fundamental physical phenomena that will lead to revolutionary advances in these areas. The program emphasizes fundamental science research and development using photons and their properties (e.g. coherence, wavelength, polarization) in ways that will significantly improve information processing capabilities for the Army in the coming decades. Several key objectives for my program include:

1. Integration of elemental optical components into "integrated optics" or "photonics" for smart, adaptive, reconfigurable sensing and image processing.

2. Extend imaging capabilities beyond the visible and infrared regions to consider advantages of the THz and ultraviolet regimes.

3. Explore the physics of optical materials with ultra-large nonlinearities. Such materials can be exploited for their well-known Kerr effects, electro-optic effects, parametric conversion, harmonic generation capability, and optical phase conjugation, among others. The goal is to develop a new class of materials that have much greater nonlinearities than existing materials, while maintaining otherwise good optical characteristics. Also, the degree of coherence can affect properties such as imaging and information content.

4. Establish new frontiers in the physics of solitons, optical vortices, left-handed materials, and light filaments.

5. Theoretical and experimental research aimed at understanding single particle motion to materials effects for high-energy, ultrashort pulsed lasers devices.

6. Investigate unconventional optics and imaging using approaches such as hybrid optical/digital systems to minimize classical optics aberrations, and adaptive optics to mitigate atmospheric distortions as well as imaging through turbid and scattering media.

Significant results obtained from these research efforts will be presented.

7679-68, Session 14

Plasmonics: the next wave of chipscale device technologies

M. L. Brongersma, Stanford Univ. (United States)

The field of optics has a long and colorful history and by now the development of advanced optical structures has enabled tremendous control over the propagation and manipulation of light waves. This control is utilized in many important technological applications, including optical microscopy, solar cells, efficient solid state light sources that could replace conventional light bulbs and plays an important role in biotechnology, medicine, and the modern day telecommunications industry. Until recently, it was thought that the manipulation of light was limited by the fundamental laws of diffraction to relatively large, wavelength scale (about 1 μm) components. Plasmonics is an exploding new field of science and technology in which the flow of light can be molded at the nanoscale using metallic nanostructures. This newly found ability is rapidly impacting every facet of optics and photonics and is enabling a myriad of exciting new technologies.

I will illustrate how many of the most successful plasmonics applications make use of at least one of two unique properties of metals. One special property of metals is that they can perform simultaneous electronic and optical functions. The second unique property of metallic structures is their ability to concentrate light to nanoscale dimensions. These properties enable a variety of new passive and active chipscale components for information transport and sensing. I will discuss the operation of several of these devices in detail. Finally, it is also important

to realize that plasmonic devices can be fabricated right now using current CMOS integrated circuit technologies.

7679-69, Session 14

Nanoplasmonics with low loss and gain

M. A. Noginov, Norfolk State Univ. (United States)

Optical loss caused by absorption in metals and a need for active control are among major challenges of modern nanoplasmonics. Both can be addressed by utilizing optical gain. In the presentation, we will discuss recent efforts aimed at the reduction of loss and stimulated emission in nanoplasmonic systems with gain.

Many plasmonic systems would benefit even more from the loss reduction techniques, which do not require optical gain. Several approaches to the gain-less solutions to the loss problem, including modification of electronic surface states and n-doping of noble metals, will be discussed at the conference.

7679-70, Session 14

Fabrication of nano- and microstructures by electroforming

A. H. Jayatissa, P. K. Desari, M. Paurazady, The Univ. of Toledo (United States)

Nano- and micro-structure electrode gaps were fabricated by an electroforming method. Thin film materials were fabricated on an insulator substrate and the microelectrodes with desired shapes were fabricated by conventional lithography method. Then the electro-formation was carried out to produce the gap structure. Controllability of the size of these gaps was investigated by modeling and experimental method. It was found that the nanostructure of wide range of metal, metal oxides and compound semiconductors can be fabricated by this method. In this study, we have attempted formation of tungsten (III) oxides, Ag, and Au. Simulation study was carried out based on finite element analysis (FEA) technique. The simulation results were verified with experimental data for the above three materials.

7679-71, Session 14

Temperature-dependent optical properties of InP nanowires in ensembles

A. J. Lohn, M. Holt, N. M. Dawson, N. P. Kobayashi, Univ. of California, Santa Cruz (United States)

The maturity of thin film technologies has made them dominant in terms of production-scale devices despite issues regarding integration of dissimilar materials. For nanowire growth single-crystalline substrates are not a requirement. InP nanowires were grown by metal-organic chemical vapor deposition (MOCVD) on non-single-crystalline platforms. The platforms were prepared by the plasma-enhanced chemical vapor deposition of a 200nm layer of microcrystalline hydrogenated silicon on a quartz substrate. Colloidal gold nanoparticles with a nominal diameter of 10nm were dispersed on the surface to catalyze nanowire growth. The nanowires were characterized using micro-photoluminescence and micro-Raman spectroscopy at various temperatures. The spectra are complicated by the presence of differing lattice types, geometries, crystal orientations, and physical interaction due to the areal density of nanowires. Optical transitions were identified as originating from quantum-confinement (QC) in zincblende (ZB) and also in wurtzite (WZ) nanowires. Bulk emission and an impurity peak as well as an exciton peak for the QC ZB were identified. Atypical band-gap dependence on temperature was observed for the QC WZ emission which only varies weakly. And transfer of energy from excitonic emission to band-edge emission was observed for the QC ZB peaks. Micro-Raman spectra are

particularly rich due to the random orientation of the nanowires which enables all Raman modes to be observed in a backscattering geometry. The spectra include signal from both ZB and WZ InP simultaneously and the WZ peaks were related to the ZB by folding the phonon dispersion along the [111] direction to approximate the [0001] direction of WZ.

7679-72, Session 14

Stability of silver nanoparticles for sensor applications

W. Cao, H. E. Elsayed-Ali, Old Dominion Univ. (United States)

Silver nanoparticles have been widely studied due to their excellent localized surface plasmon resonance properties and potential use in optical, chemical, and biological sensors. Recently, electron beam lithography (EBL) was utilized by various research groups to fabricate Ag nanoparticle arrays with precisely controlled shape, size, and inter-particle distance, thus allowing development of sensing devices. To date, there have been numerous reports on the fabrication and optical properties of Ag nanoparticles. However, very few studies have focused on their stability, which in turn determines the long term durability and reliability of nanoparticle based sensors. In the present study, the stability of silver nanoparticles on indium tin oxide coated glass substrates under atmospheric condition was investigated. The EBL-fabricated nanoparticles were exposed to laboratory air at room temperature for 12 weeks as well as stored in vacuum for the same period of time for comparison. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) analyses were carried out periodically during the aging process. The energy dispersive spectroscopy (EDS) spectra revealed a high concentration of sulfur in the Ag nanoparticles exposed to laboratory air for 12 weeks at room temperature, indicating the formation of Ag2S on their surfaces. Moreover, SEM and AFM results showed morphology change and void formation in Ag nanoparticles exposed to the laboratory air. No sulfur was detected and no obvious morphology changes were observed on Ag nanoparticles stored in vacuum. The present work clearly shows the need to consider the stability under ambient conditions when using Ag nanoparticles for sensors.

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7680-01, Session 1

Nanoscale characterization of materials with novel infrared spectroscopy

C. Prater, K. Kjoller, D. Cook, Anasys Instruments (United States)

Infrared spectroscopy is one of the most widely used techniques in materials characterization, but the spatial resolution is constrained to the micron scale due to diffraction limits. We have developed instrumentation to overcome these limits based on a novel IR source combined with atomic force microscopy (AFM). The instrument illuminates a small region of a sample with IR radiation. IR absorption by the sample generates local heating that is sensed by an AFM tip. IR absorption spectra are created by plotting the heat signal detected by the AFM as a function of wavenumber. The AFM can also be used to image a sample and then select regions of areas of interest for subsequent measurements of IR spectra. We will share results of this technique applied to a variety of polymer samples including multi-layers and multi-component blends over the range of 1000-4000 cm-1. We will present AFM images and spatially resolved IR spectra that allow analysis of morphological and chemical structure of materials at the micro and nano scale.

7680-02, Session 1

Portable and rapid Raman bio-agent identification

M. Lesaicherre, GE Security (United States)

Using Raman spectroscopy, the StreetLab MobileTM can be used to identify a broad range of chemical substances such as toxic industrial chemicals, explosives, and narcotics. Here we present the how Surface Enhances Raman Spectroscopy was integrated with the StreetLab MobileTM to allow for rapid biological pathogen identification.

A washless, liquid-based sandwich immunoassay employing magnetic sample concentration will be described for use in the identification of biological pathogens including E. coli and anthrax. Specifically, micrometer sized antibody-coated magnetic capture beads to concentrate the pathogen of interest, and antibody-coated nanometer sized SERS tags for sensitive identification of the captured pathogens defines this assay. The reagents are lyophilized to ensure long-term stability under a wide range of temperatures, and the biological identification capabilities require little sample preparation, minimizing hands-on time and maximizing the ease of use. Results from 3rd party validation will be presented. The applicability of this technology in the area of Homeland Protection will also be discussed.

7680-03, Session 1

Universal explosive detection system for homeland security applications

V. Y. Lee, E. E. A. Bromberg, L-3 CyTerra (United States)

L-3 Communications CyTerra Corporation has developed a high throughput universal explosive detection system (PassPort) to automatically screen the passengers in airports without requiring them to remove their shoes. The technical approach is based on L-3 CyTerra' innovative new energetic material detection (EMD) technology. By observing the results of rapid sample heating with an infrared detector, one can distinguish the deflagration or decomposition of an energetic material from other clutters such as flammables and general background substances. This becomes the basis for a universal explosive detection system that does not require a component library and is capable of detecting trace levels of explosives with a low false alarm rate. The PassPort is configured as a simple turnstile type device and integrates a non-intrusive aerodynamic sampling scheme that has been shown to be capable of detecting trace levels of explosives on shoes. A detailed description of the detection theory and the automated sampling techniques, as well as the field test results, will be presented.

7680-04, Session 1

A spoof detection method for contactless fingerprint collection utilizing spectrum and polarization diversity

G. Abramovich, K. Harding, M. Ganesh, S. Manickam, GE Global Research (United States); A. Vemury, U.S. Dept. of Homeland Security (United States)

The paper presents a mult-ispectral, multi-polarization optical and image analysis spoof detection technique for a contactless fingerprint capture system. While a multispectral solution has been proven for contact fingerprint imagers, the current method relies on frustrated total internal reflection that requires a planar fingerprint, achieved by contact. The multispectral imaging method is based primarily on the difference in the spectral absorption profile between a real finger and a fake one. This paper will describe the expansion this capability using blue and red light with contactless imaging. This new method then uses images at various rotated linear polarizations (each image representing a different values of specular and diffuse components), which are used to create the feature vectors representing the spectral and polarization diversity. We will discuss the results of testing the method using normalized standard deviations and additional statistical moment based feature extraction algorithms. The software extracts complex wavelet transforms (CWT) and FFT features from the images and builds a supervised learning method to train Support Vector Machines (SVM) classifiers.. Experimental data was collected using a representative silicon based fake finger. Fake and actual fingerprints were collected using individuals with a large diversity in skin tone, age, finger dimensions. Our initial results, with an error rate of **%, are promising and show that using the polarization diversity can enhance the spoof detection performance. Major experiments are expected to evaluate the system with a diversity of spoofing materials and a large number of individuals.

7680-05, Session 1

Field-rugged sensitive hydrogen peroxide sensor based on tunable diode laser absorption spectroscopy (TDLAS)

M. B. Frish, J. R. Morency, R. T. Wainner, W. J. Kessler, M. A. Druy, Physical Sciences Inc. (United States)

Trace gas sensing by Tunable Diode Laser Absorption Spectroscopy (TDLAS) is a robust and reliable spectroscopic technology for industrial process monitoring and control, quality assurance, environmental sensing, plant safety, and infrastructure security. Novel adaptations of mature TDLAS platforms address increasingly difficult applications that demand sensing multiple target gases in spectroscopically-complex gas mixtures with high spatial or temporal resolution in harsh environments.

This paper describes a field-portable near-IR TDLAS sensor for vapor phase hydrogen peroxide (H_2O_2). Peroxide, known as an ingredient of IEDs, is used for decontaminating areas after accidental or purposeful exposure to hazardous biological materials. These areas include buildings, laboratories and hospital rooms, as well as barrier isolators utilized in pharmaceutical, medical and food processing facilities. During

decontamination, a sterilization system fills ambient air with water and peroxide vapor. The peroxide concentration typically must exceed several thousand ppm for tens of minutes, and subsequently diminish below 1 ppm.

Unlike H2O2 analyzers that probe spectral bands, TDLAS probes individual spectral lines. Thus, rather than being confounded by cross-sensitivity from the multitude of neighboring and overlapping H2O2 and H2O spectral lines, the TDLAS analyzer capitalizes upon these features to measure both vapors using a single DFB laser source. The H2O2 range is approximately 1- 10,000 ppm. It is an autonomous, rugged instrument providing real-time data. Its performance has been verified, and approximate calibration achieved, via application of Henry's law in a closed-loop liquid/vapor equilibrium apparatus, and by comparing the measurements in barrier isolators against broadband NIR and electrochemical sensors.

7680-06, Session 1

Mid-IR Tm-fiber laser for laser-induced plasma spectroscopy of organic and biological materials

M. Baudelet, C. C. C. Willis, L. Shah, M. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Laser-Induced Breakdown Spectroscopy has been evolving since its first analytical use in 1963. The evolution of lasers has pushed the technique to adapted regimes of ablation and better analytical performances for each kind of samples. In this study, we show that a 2 µm Tm fiber laser has many benefits for LIBS: (i) compactness, (ii) better eye safety, and (iii) emission that can be tuned to water absorption peaks which has great potential for the ablation of water-based biological and/or organic samples.

Our study is focused on the LIBS analysis of organic samples and the benefits of this fiber laser in analytical applications. We use a nanosecond Tm fiber laser delivering pulses at 2 µm at a repetition rate of 20 kHz. The average power on the target is 2.3 W. We studied the analytical properties of the plasma on metallic, graphite, organic and biological samples to better understand the effect of a nanosecond 2 µm ablation of organic samples on their spectroscopic signatures (atomic and molecular).

Whereas the usual nanosecond LIBS configurations in the near-IR and visible wavelengths have issues with molecular formation between atmospheric nitrogen and carbon containing plasmas, our results show that mid-IR excitation shows low to no interfering signal from any molecular signal that is not representative of carbon-based samples (graphite and organic analytes). This lack of interference shows the potential of mid-IR LIBS for detection and identification of organic samples under normal atmosphere.

7680-07, Session 1

Low-noise moisture meter with high-speed LED techniques

R. Aikio, J. O. Malinen, H. Lindström, P. Suopajärvi, VTT Optical Instruments (Finland)

Near infrared (NIR) spectroscopy can provide inexpensive, rapid and contact-free chemical content measurements for on-line, hand-held and laboratory applications. Traditionally multiwavelength NIR analyzers are based on incandescent lamp light sources with rotating filter wheels, even though designs relying on lamp technology and moving parts mean larger size, require frequent maintenance and eventually limit measurement speed of the system. Today, optical power and available wavelength range of LEDs enable their use in chemical content analyzers. In this publication, a paper moisture meter with high speed LED techniques is presented. A prototype developed at VTT utilizes an extended InGaAs detector to measure diffuse reflection at four

NIR wavelengths ranging from 1.2 to 2.1 µm. Source LED currents are amplitude modulated with fixed sinusoidal frequencies. Optical signals at each wavelength are demodulated from the detector signal using real-time digital lock-in detection method on an FPGA. Moisture content is calculated and displayed on the embedded platform. The design allows very high speed operation, where the result is updated every 1 ms. Performance of the prototype system was studied by measuring a set of known sealed paper samples. Paper moisture measurement accuracy was 0.14, repeatability 0.01 and 2 noise 0.04 moisture percent. Laboratory tests showed that channel crosstalk after detection is below background noise level. The measured signal-to-noise ratios per channel were 70 - 85 dB when all LEDs were on. The overall performance equals or exceeds the level of incandescent lamp systems. The developed system forms a good basis also for other content measurements.

7680-08, Session 1

Fiber-optic coupled hyperspectral imaging techniques applied to the quantification of fluorophores in multi-point sensing

R. D. Driver, K. P. Grim, J. Zakrzewski, Headwall Photonics Inc. (United States)

A multi-channel fiber-optic hyperspectral fluorimeter has been developed, which can allow the concentration of fluorophore tagged molecules to be measured as the molecules are changed or amplified over time by techniques such as polymerase chain reaction. Such multiplexed measurements enable new capabilities in the area of bio-technology and fluorescence based detection applications in multi-well and multi-capillary sampled systems. A highly optically-efficient miniaturized fiber-optic micro-fluorimeter fluorescence cell has been developed for operation with a hyperspectral based detection system. Multiple such cells are illuminated with a single excitation laser and the resulting fluorescence signal from each cell is separately coupled to a single hyperspectral imager, outfitted with a board-level EMCCD camera. The parallel acquisition of multiple fluorescence signals on a single detector and the use of various optimized illumination and detection schemes, allows the concentration of the fluorophore tagged molecules in the samples to be measured over a 5 order of magnitude concentration range with high detection linearity. Fluorescence detection performance data of the multiplexed system is compared to theoretical predictions and system optimization is discussed, comparing different illumination and detection schemes. The extension of the technique for use with multiple fluorophores and multiple excitation lasers is discussed.

7680-09, Session 2

Calibration maintenance and transfer using multiple linear regression-based modeling of new spectral variances

S. B. Cole, J. H. Kalivas, Idaho State Univ. (United States)

Maintenance of a multivariate calibration model is essential to account for changing conditions such as temperature, particle size, and instrumental drift. In calibration transfer, models developed on a primary instrument sometimes must be used to predict samples collected on a secondary instrument. This poster reports on variations of a technique using multiple linear regression on standardization samples measured under both the primary conditions/instrument, that is to say original, and secondary conditions/instruments, that is to say new, to estimate a set of correction parameters to be added to each new spectrum measured under the secondary conditions/instruments in order to appear as if the spectrum was measured under the primary conditions/instrument. A multitude of possible correction parameters were explored including polynomials, derivatives and trigonometric functions. Correction parameters were calculated across the full spectrum, across spectral windows and one wavelength at a time. Best results were obtained via moving spectral windows. Multiple methods for selecting optimal correction terms and

window size are outlined. Methods for weighting standardization samples for optimal correction of each new sample are presented. Results are based on near infrared spectra for calibration maintenance due to changes in temperature and calibration transfer from an instrument to another instrument.

7680-10, Session 2

Net analyte signal as a prediction error proxy for multivariate calibration model selection

J. H. Kalivas, Idaho State Univ. (United States)

In spectroscopy, net analyte signal (NAS) is the useful analyte portion of a measured spectrum orthogonal to the non-useful information originating from other sources of variation such as interferents. Once the NAS has been computed, numerous analyte specific figures of merit can be calculated such as selectivity, sensitivity, and detection limit. The main issue with NAS is to obtain spectra without the analyte. Several methods to obtain these spectra and perform NAS calibration have been proposed. An interesting perspective on NAS is that the NAS vector is inherent to the sample matrix and, thus, it should be independent of the calibration method. That is, the NAS can be estimated from the model regression vector and the NAS should be the same whether a partial least squares (PLS) or ridge regression (RR) model is used to estimate the NAS. If the regression vector is good (close to truth), then the NAS vector should be the same regardless of the modeling method. Many methods of multivariate calibration, such as PLS or RR, require selection of meta-parameters (factors for PLS and the ridge value for RR). Selection of the meta-parameter is typically performed by a prediction error criterion such as the standard error of prediction (SEP) commonly obtained by a cross-validation process. This talk describes a new method using NAS to determine optimal meta-parameters. As with any NAS procedure, a good spectral representation of the space without the analyte is critical. Examples based on near infrared spectra are provided.

7680-11, Session 2

Multiple uses of Tikhonov regularization in multivariate calibration

J. H. Kalivas, Idaho State Univ. (United States)

Building a multivariate calibration model is typically accomplished using partial least squares (PLS), principal component regression (PCR) or ridge regression (RR), which is actually the standard form of Tikhonov regularization (TR). These approaches are commonly used in a full variable mode (full wavelengths for spectroscopic data). Sometimes wavelength selection is used to enhance the predictability of the model. Calibration transfer and maintenance are important aspects of multivariate calibration and describe the problem of being able to take an existing model (determined under primary conditions) and updating this primary model to handle new secondary conditions such as a new instrument or environmental conditions. This talk overviews TR in its ability to individually or in simultaneous combination build a primary calibration model, update the primary model to new secondary conditions, and/or select wavelengths to reduce prediction error. Examples based on simulated data and near infrared spectroscopic data are used.

7680-12, Session 3

Handheld hyperspectral imager

H. K. Saari, VTT Technical Research Ctr. of Finland (Finland); J. O. Malinen, VTT Optical Instruments (Finland); V. Aallos, C. Holmlund, J. Mäkynen, VTT Information Technology (Finland)

VTT Technical Research Centre of Finland has developed a new low cost handheld staring hyperspectral imager for applications previously blocked by high cost of the instrumentation. The system is compatible with standard video and microscope lenses. The instrument can record 2D spatial images at several wavelength bands simultaneously. The concept of the hyperspectral imager has been published in the SPIE Proc. 7474. The prototype fits in an envelope of 100 mm x 60 mm x 40 mm and its weight is ca. 300 g. The benefits of the new device compared to Acousto-Optic Tunable filter (AOTF) or Liquid Crystal Tunable Filter (LCTF) devices are small size and weight, speed of wavelength tuning, high optical throughput, independence of polarization state of incoming light and capability to record three wavelengths simultaneously. The operational wavelength range with CCD or CMOS sensors is 200 - 1100 nm and spectral resolution is 2 - 10 nm @ FWHM. Similar IR imagers can be built using InGaAs, InSb or MCT imaging sensors. The prototype spatial resolution is 480 x 750 pixels. The system contains control system and memory for image data acquisition. It operates either autonomously recording hyperspectral data cubes continuously or controlled by a laptop computer via USB2 port. The prototype is configured for the spectral range 500 - 900 nm, and it was tested with microscope and video objectives in medical, food and other applications. The design of the hyperspectral imager, characterization results as well as sample analysis examples will be presented.

7680-13, Session 3

Comparative performance studies between tunable filter and push-broom chemical imaging systems

J. O. Malinen, VTT Optical Instruments (Finland); G. J. Kemeny, Middleton Research (United States); Z. Shi, C. A. Anderson, Duquesne Univ. (United States)

Multiple instrumental techniques are today available for recording hyperspectral data of solid samples for chemical imaging applications. Stationary samples are frequently measured using staring or tunable filter imagers (e.g. LCTF), which record complete 2D images sequentially for each wavelength. Push-broom imagers are useful for measuring moving sample material, thanks to capturing instantaneous line images with full spectral information linked to every pixel. Today push-broom imagers provide alternative high speed approach for studying laboratory samples too, by using sample movement stages synchronized to imager operation. Furthermore, VTT Technical Research Centre of Finland is currently developing high speed hyperspectral techniques using Fabry-Perot interferometer, aiming for high speed applications without the need for sample movement.

With such a variety of instrumental techniques it is useful to understand differences of each technique in user point of view. This paper reports instrument characterization measurements, which were recently arranged to provide comparative information on different hyperspectral chemical imaging systems. The instruments studied included both tunable filter and push-broom techniques: MatrixNIR by Spectral Dimensions, SisuChema by Specim and the Fabry-Perot based imager prototype from VTT. The characterization procedure was designed to study instrumental noise, signal-to-noise ratio, linearity and spectral as well as spatial resolution. Finally, a pharmaceutical tablet sample was measured with each instrument to demonstrate speed of measurement in typical application. In spite of differences in wavelength ranges and camera technologies used (InGaAs vs MCT) the results provide interesting information on instrumental pros and cons, which may be useful for selecting most suitable instrumentation for user applications.

7680-15, Session 3

Detection of flexographic inks using NIR AOTF-based hyperspectral imaging

R. Leitner, T. Arnold, M. De Biasio, Carinthian Tech Research AG (Austria)

Near-infrared (NIR) spectroscopy is a widely used method for material

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identification for laboratory and industrial applications. While standard spectrometers only allow measurements at one sampling point at a time, NIR Spectral Imaging techniques can measure, in real-time, both the size and shape of an object as well as identify the material the object is made of.

The online classification and sorting of recovered paper with NIR Spectral Imaging (SI) is used with success in the paper recycling industry throughout Europe. Recently, the globalisation of the recycling material streams caused that water-based flexographic-printed newspapers mainly from UK and Italy appear also in central Europe. These flexo-printed newspapers are not sufficiently de-inkable with the standard de-inking process originally developed for offset-printed paper. This de-inking process removes the ink from recovered paper and is the fundamental processing step in paper recycling. Thus, flexo-printed newspapers are a growing problem for recycling as they reduce the quality of the produced paper if their amount exceeds a certain limit of the recovered paper.

This paper describes the chemometric model development using an NIR AOTF based hyperspectral imaging system for the detection of flexographic printing inks. The achieved accuracy with the AOTF based system is above 95%. Subsequently the model was transferred to an industrial spectrograph based sorting prototype evaluating the application with an instrumentation that is suitable for the recycling industry. Again an accuracy of over 95% on the object level was achieved for a sorting test including physical sorting using an array of air nozzles.

7680-16, Session 3

Field demonstration of an infrared adaptive spectral imager for direct detection of spectral signatures and hyperspectral imagery

N. Goldstein, M. J. Fox, S. M. Adler-Golden, B. Gregor, J. Lee, Spectral Sciences, Inc. (United States)

Field test results are presented for a prototype long-wave adaptive imager that provides both hyperspectral imagery and contrast images based on the direct application of spectral detection algorithms in hardware. Programmable spatial light modulators make it possible to adjust spectral, temporal and spatial resolution in real time, as well as implement detection algorithms directly in the digitally controlled sensor hardware. Operating parameters can be optimized in real time, in order to capture changing background and target evolution.

The optical system, consisting of two machined toroidal surfaces, a single-element detector and a digital micromirror device (DMD), is compact and potentially robust. It has no macro-scale moving parts, and is thus relatively rugged and suitable for field use. The digital micromirror array is used to select spatial and spatial pass bands under computer control. Contrast images are obtained by applying an analog transmission function to the DMD using grey scales. Any linear detection algorithm can be implemented in hardware, including traditional methods such as matched filters, orthogonal subspace projection, and principal component analysis.

Three modes of operation were demonstrated. One- and two-dimensional spectral contrast imagery was obtained using target and scene spectra collected in hyperspectral imager mode. Two dimensional matched-filter imagery was used to visualize and detect target gases in typical outdoor scenes.

Methods are described to make generalized filters that optimize signal/noise for in-hardware detection. Implementation of detection algorithms at the data collection step may provide advantages in optimizing data collection duty cycles, reducing data processing requirements, and suppressing background signals.

7680-17, Session 3

Spectral imaging using tunable laser source

E. K. Margalith, L. K. Nguyen, OPOTEK, Inc. (United States)

NIR Spectral Imaging is an important analytical tool for a wide variety of industries, including agriculture, remote sensing (environment monitoring), health care, chemical and pharmaceutical for both research and development and manufacturing quality control. In recent years table-top laboratory instruments were introduced, in which broadband light source is used for the illumination and the spectral selection is done by filters or gratings. However, the transition from an R&D instrument to the manufacturing floor is slow, due to inherent limitations of these instruments.

We have developed a spectral imaging instrument that utilizes a tunable laser as the illumination sources, with the goal of addressing the constrains of manufacturing environment. The results are higher spectral resolution (<1.5nm), better signal-to-noise ratio, fast data acquisition (seconds), and low power on the sample (i.e., no sample heating). Actual wavelengths are recorded and the reflectance signal is calibrated and corrected for linearity at each wavelength in real-time, without the need for a pre-measurement calibration. The instrument is very compact, fully automated and can be used to analyze stationary, as well as moving objects.

7680-19, Session 3

Design and calibration of aberration-corrected high-efficiency hyperspectral NIR and SWIR imagers for airborne applications

K. M. Didona, D. P. Bannon, Headwall Photonics Inc. (United States)

A series of next-generation ruggedized and lightweight high-efficiency, hyperspectral analyzers have been developed for full airborne deployment. With peak efficiency greater than 90%, the NIR (900-1700 nm) and SWIR (1000-2500 nm) designs have been optimized for maximum system efficiency in light-limited operations while retaining the low stray-light and low-aberration specifications characteristic of fully reflective optical systems. System designs have been optimized to eliminate keystone and smile image aberrations within a totally reflective, concentric sensor design. Overall sensor performance will be presented including the impact of custom-designed fore-optics developed for these imager designs. The ruggedized designs include tall image slit assemblies and atheramalized construction for imaging in harsh environments. To attain the highest required hyperspectral sensor performance, system design, alignment and calibration are key attributes which are considered to achieve full airborne robustness.

7680-20, Session 4

Thermopile linear array for spectroscopy applications

A. D. Levin, W. Baer, S. Harrigan, J. Zewicke, R. Toth, Dexter Research Ctr., Inc. (United States)

We have designed, simulated, and fabricated an uncooled linear array of 66 infrared detectors using MEMS techniques. CMOS compatible Poly-Si thermoelectric material is utilized. Numerical simulations optimize the geometry and physical parameters for the thermopile materials. The pixel dimensions are 2.0 mm x 0.45 mm with 0.5 mm pitch. We obtained excellent performance in Nitrogen environment: $D^* = 1.1 \times 10e8$ cmHz$^{1/2}$/W; t=42 ms; and cross talk of <15 %. Measured performance is comparable to, and in some respects exceed, the performance of thermopile linear arrays based on Bi and Sb materials. Arrays are packaged for integration with an existing liquid spectrometer.

7680-21, Session 4

CMOS capacitive sensing circuit for closed-loop control of wide tuning range microspectrometers

M. Susli, D. K. Silva, F. Boussaid, J. M. Dell, The Univ. of Western Australia (Australia)

A major issue with tunable Fabry-Perot filter-based micro-spectrometers realised using micro-electromechanical systems (MEMS) is obtaining a robust, low cost measurement of the cavity length and hence transmitted wavelength. We propose a novel differential capacitive CMOS sensing circuit to determine the relative position of mirrors in a MEMS-based Fabry-Perot micro-spectrometer. This real-time measurement enables in turn robust operation through closed-loop control of the micro-spectrometer's center wavelength. The micro-spectrometer is based on a novel MEMS flexure design that requires an AC source (1MHz, up to ~25Vpp) to achieve a large dynamic range in the SWIR band (1615nm to 2425nm). A lock-in technique is implemented to detect the relative change in capacitance against an undriven structure, using an RF (100mV at 200MHz) reference signal. Multiplicative feedback is used to compensate for noise and offset induced by process variations. At the mixer, interferences associated to the large driving signal are eliminated using a high-pass filter. This electrical detection of the Fabry-Perot cavity length can be applied to the individual flexures supporting the movable mirror, also allowing control of tip instabilities.

7680-22, Session 4

A novel high-brightness, broadband light-source technology from the VUV to the IR

S. F. Horne, M. M. Besen, W. Holber, M. J. Partlow, D. K. Smith, J. Ye, H. Zhu, Energetiq Technology, Inc. (United States)

A novel technology has been developed which enables high-brightness, broadband light output from the VUV to the IR spectral regions. A focused laser is used to sustain a high-pressure xenon discharge inside a bulb, creating a smaller, hotter discharge than can be obtained by using an electrically-driven discharge. This allows for continuous output down to 120 nm wavelength and into the infrared. Application areas include hyperspectral imaging, standoff detection, surveillance, bioanalytical instrumentation, microscopy, and materials studies.

Laser-driven optical discharges were first investigated over 30 years ago, providing the initial technical understanding of such discharges. However it took the convergence of two separate elements - the availability of low-cost, high-efficiency CW diode lasers; and a market need for high-brightness, broadband light source - to provide the impetus for further development in this area. Using near-IR CW diode lasers at power levels from 50 W to over 2000 W, we have generated high-pressure xenon discharges having temperatures as high as 10,000 C. The optical brightness of these discharges can be over an order of magnitude higher than those obtainable from the brightest xenon arc lamps, and can be several orders of magnitude brighter than deuterium lamps. Results from modeling of these discharges as well as experimental measurements will be presented.

7680-23, Session 4

Mid-IR sensing using external cavity quantum cascade lasers

T. Day, Daylight Solutions, Inc. (United States)

Commercially available quantum cascade semiconductor materials continue to mature. When integrated into external cavity quantum cascade laser (ECqcL) geometries, these laser systems are now providing near-continuous coverage throughout the entire 3-12 um regime. Such coverage enables molecular detection systems to enjoy high sensitivity and selectivity. Individual lasers have been demonstrated to provide > 270 wavenumbers of tuning from commercially available systems. Wide tuning ranges have also been demonstrated at wavelengths in the 3-4um regime. In addition, phase continuous (mode-hop-free) tuning allows for extremely high resolution spectroscopy to be performed throughout the mid-IR. Daylight will review the most up-to-date results regarding wavelength coverage, tuning range and power levels achieved from ECqcL systems. Daylight will also provide recent results in sensitivity and coverage from their multi-species Swept Sensor and photoacoustic detection platforms.

7680-24, Session 4

Infrared intracavity laser absorption spectrometer

G. Medhi, R. E. Peale, A. V. Muravjov, J. W. Cleary, Univ. of Central Florida (United States); O. J. Edwards, Zyberwear, Inc (United States)

No spectral sensing method currently has sufficient sensitivity to detect vapors of low vapor-pressure compounds such as explosives. An opportunity is Intracavity Laser Absorption Spectroscopy (ICLAS) at IR wavelengths. We propose such a system based on multi-mode external-cavity quantum cascade lasers and a scanning Fabry-Perot spectrometer to analyze the laser mode spectrum in the presence of a narrow band intracavity absorber. This paper presents results of numerical solution of laser rate equations that support feasibility of kilometer effective active-cavity path lengths and sensitivity to concentrations of 10 ppb. This is comparable to the saturated vapor pressure of TNT. System design considerations and first experimental results are presented at 10 and 70 micron wavelengths.

7680-25, Session 4

Micro-electron spin resonance (ESR/EPR) spectroscopy

C. J. White, Active Spectrum, Inc. (United States)

Electron Spin Resonance (ESR / EPR) is the only direct method for measuring free radicals, reactive molecules with unpaired electrons that cause the oxidative breakdown of oils, food products, and also play a role in the biochemistry of disease. We discuss a recently developed miniature, high sensitivity ESR spectrometer called Micro-ESR. The technology promises to revolutionize the accessibility of ESR spectroscopy for industrial and scientific users.

We discuss trade-offs in the miniaturization of ESR spectrometers, particularly, the limits imposed by the magnetic field and the sample type. We present measurement results showing the sensitivity limits of the Micro-ESR spectrometer, with representative spectra from TEMPOL in polar and non-polar solvents. Further experimental results will be presented showing the magnetic field homogeneity of the miniature spectrometer.

7680-26, Session 5

Ultra-sensitive NIR-spectrometer based on frequency up-conversion detector

L. Ma, O. T. Slattery, X. Tang, National Institute of Standards and Technology (United States)

Due to high noise and low sensitivity of single photon detectors in near the infrared (NIR) range, the performance of NIR spectrometers is limited in comparison to that in visible region. We have implemented a NIR spectrometer based on a frequency up-conversion detector.

This detector uses a 5-cm periodically poled lithium niobate (PPLN) waveguide to convert signal photons at 1310 nm to 710 nm by using a pump laser around 1550 nm. The converted photons at 710 nm are then detected by a silicon-based avalanche photodiode (Si-APD). The overall detection efficiency is 32%. According to energy conservation condition in the conversion process, tuning the pump wavelength allows us to trace out the spectrum of the signal. Different to other types of spectrometer, the up-conversion spectrometer does not need any dispersive element or tunable narrow-band filter, and has high transmission efficiency. Si-APD has very high detection efficiency at 710 nm (65%) and low dark count rate. Therefore, the spectrometer's sensitivity is as high as -126 dBm, which is at least three orders-of-magnitude higher than that of any commercial optical spectrum analyzer in this range. The spectrometer's resolution is determined by the acceptance bandwidth of the PPLN waveguide, which is 0.25 nm in our case.

In this paper, we describe the NIR spectrometer based on a frequency up-conversion detector, and experimentally study its detection efficiency, sensitivity, resolution and its dynamic operation range. We also demonstrate its performance by applying it into the spectra measurement of signals at single photon level.

7680-27, Session 5

Portable open-path optical remote sensing (ORS) FTIR instrumentation miniaturization and software breakthroughs for point and click real-time analysis

P. G. Zemek, S. V. Plowman, Midac Corp. (United States)

Advances in hardware and software have enables the development of portable point and click OP-FTIR systems that weigh just 16 lbs. These field deployable systems are ideal for first responder, military, and screening in optical remote sensing applications. The hardware has enabled the development of a very lightweight, rugged, fast scanning OP-system with inter-changeable detectors coupled to new forward reference type model software to provide point and click technology. There is no longer any need for synthetic background generation as the system uses highly accurate instrument line shape convolutions for modeling a single calibration spectrum. Data retrievals are performed directly on single beam spectra. Applications include the use of IR sources such as ignited material, solar occultation, "hot" sources, and come in mono- and bi-static configurations and their lightweight sources or targets. Data from numerous applications will be presented.

7680-28, Session 5

Performance trade-off modeling for a handheld FT-IR spectrometric vapor identifier

D. W. Schiering, Smiths Detection (United States); R. G. Messerschmidt, Reflective Sciences, Inc. (United States); P. Zou, Smiths Detection (United States)

Emerging chemical threats to homeland security challenge the specificity of sensor-based chemical detectors. As the number of chemicals to detect increases, the false alarm rates of these sensor-based systems tend to increase and the usefulness of the detector in real world situations declines. The infrared (IR) absorption spectrum of a material is a physical constant and highly specific for the molecule of interest. For many years, IR spectra have been used by chemists to identify unknowns based on comparison with spectra of known materials and to determine the presence of chemical functional groups through spectral interpretation. IR spectroscopy is well suited for the identification of broad-based chemical threats. This discussion shall concern the conceptual development of a hand held IR spectroscopy system for the identification of chemical vapor threats. The discussion shall focus on design tradeoffs where miniaturization is of paramount importance. Quantitative IR absorption spectra of threat compounds were used to

model absorption line strengths at moderate spectral resolutions. IDLH detection limits targets, acquisition time, etendué, and signal-to-noise parameters guided the concept design and pathlength of a long path gas cell used in conjunction with a hand held FT-IR spectrometer.

7680-29, Session 5

High-speed resonant FTIR spectrometer

J. Rentz Dupuis, D. L. Carlson, J. R. Engel, OPTRA, Inc. (United States)

OPTRA is developing a high speed resonant Fourier transform infrared (HSR-FTIR) spectrometer for surface contaminant measurements via time resolved thermal luminescence. This system incorporates a multipass reciprocating interferometer and a resonant mirror structure to accomplish the scanning. The configuration and associated reduced required physical stroke length for a given spectral resolution allows for the use of high speed resonant actuators such as piezo stacks. Because the spectral range is limited only by the spectral transmission and reflection properties of the components, this system can be made as broadband as a typical FTIR spectrometer system. For this application, the system will be designed for the 700 - 1400 cm-1 spectral range with 8 cm-1 spectral resolution.

This paper presents a conceptual design of the HSR-FTIR system with particular attention to position based sampling of a high speed sinusoidal scan.

7680-30, Session 5

Sensitivity analysis of an assembled Fourier transform microspectrometer

J. Sin, W. H. Lee, H. E. Stephanou, The Univ. of Texas at Arlington (United States)

This paper presents a sensitivity analysis of Fourier Transform microspectrometer. Precision alignment of optical components is a critical factor to achieve high contrast fringes and sensitive measurement in MEMS based spectrometer. While many MEMS based optical systems relies on their positional and angular alignment upon precisely micromachined features, however the silicon micromachining such as Deep RIE process often ends up with fabricated vertical structures in error range of +/-1 degree. When these features are used as optical components or mating parts for further assembly processes, they cause angular misalignment that makes deviation of beam paths. Hence it is very important to quantify how misalignments accumulate and propagate from one component to another. We have analyzed the effect of angular misalignment with respect to detector signals and performance of the device. Optical path of the device was modeled to calculate the deviation of beams at the detector plane, and the optical power falling onto the detector was calculated. This analysis was applied on ARRI's mircrospectrometer to guide design and manufacturability. The FT microspectrometer is composed of a microoptical bench, which was fabricated with a Deep RIE (Reactive Ion Etching) process on an SOI (Silicon On Insulator) wafer, a linear translation stage with an electrothermal actuator, moving and fixed silicon mirrors with gold coating, a silicon beamsplitter, and a detector. The size of the assembled spectrometer is 10mmx10mmx2mm, and the spectral range of NIR spectrometers is 1100-2000nm, respectively.

7680-31, Session 5

MEMS and piezoactuator-based Fabry-Perot interferometer technologies and applications at VTT

J. E. Antila, A. Miranto, H. K. Saari, VTT Optical Instruments (Finland); M. Laamanen, VTT Technical Research Ctr. of Finland (Finland); M. Blomberg, VTT Elektroniikka (Finland)

Miniaturized microspectrometers covering spectral regions from UV to thermal IR are of interest in several application fields. For these purposes VTT has extensive experience in developing tuneable MEMS-based Fabry-Perot Interferometers (FPIs) especially for gaseous carbon dioxide measurements at 3.8 - 4.2 µm. Lately VTT has further developed its MEMS technology to enable manufacturing of the first UV/VIS/NIR range tuneable surface micromechanical Fabry-Perot Interferometers and also a new type of a component for covering wavelengths from 1 to 5 µm. In this paper the basic construction of the components are introduced and the applications and relating measurement results are presented. A low-cost configuration utilizing a VTT-developed MEMS-thermopile detector is also presented. Possibilities to further extend the wavelength region towards longer wavelengths and on the other hand the possibilities to increase the level of integration of a spectrometer are discussed. We have also developed new Piezo-controlled FPI components for both single-point and imaging applications. These components can be made larger and fast and they can utilize a wider selection of materials. Component construction is explained and the newest results are presented from application studies. The possibility to use MEMS FPIs in imaging applications is also discussed. Finally the concept of extending the wavelength range of FPIs to cover a wider region than the Free Spectral Range using additional filters or cascaded FPIs is presented with examples.

7680-32, Session 5

Portable NIR/MIR Fourier-transform spectrometer based on a common path Lamellar grating interferometer

F. Merenda, S. Bühler, H. Farah, G. Boer, ARCoptix S.A. (Switzerland); T. Scharf, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Spectroscopy with portable systems is a fast developing field. While Fourier-transform spectrometers are well-known to achieve superior performance than dispersive spectrometers in the infrared (IR) wavelength range, they are typically bench-top sized laboratory instruments. We report on the recent development of a compact and rugged near- and mid-IR Fourier transform spectrometer based on a common path lamellar grating interferometer. The heart of this interferometer is a microfabricated binary grating with variable depth, actuated by high precision micro-mechanics. The intensity in the reflected zero order is recorded as a function of the grating depth, and then Fourier transformed in order to recover the spectrum. Light is brought to the interferometer module (as small as 35 mm x 35mm x 65mm) by 600µm core fibers, and the required nanometric control of the grating depth is ensured by an embedded mono-mode laser. Current devices allow up to 1.5 mm optical path difference, thus enabling a resolution of 8cm-1. The wavelength range is mainly limited by the detector performance and fiber transmission characteristics, as no beam splitter is needed as in more conventional instruments based on Michelson interferometers. In the near-IR, a wavelength range of 0.9-2.6µm is achieved with InGaAs detectors, while MCT detectors are used for the mid-IR wavelength range from 2 to 5µm, and possibly beyond. Several measurement examples are presented (including transmission spectra of gases) to illustrate the performance of this portable infrared spectrometer in terms of sensitivity, stability, resolution and signal-to-noise ratio.

7680-33, Session 5

CMOS-compatible LVOF-based visible microspectrometer

A. Emadi, H. Wu, Technische Univ. Delft (Netherlands); S. Grabarnik, Consultant (Netherlands); G. de Graaf, Technische Univ. Delft (United States); R. F. Wolffenbuttel, Technische Univ. Delft (Netherlands)

Single-chip optical micro-spectrometers have huge potential in many applications. A small Linear Variable Optical Filter (LVOF) integrated with an array of optical detectors is a very suitable candidate for a high-resolution micro-spectrometer. The LVOF is basically a one-dimensional array of many Fabry-Perot (FP)-type of optical resonators. Rather than a huge number of discrete devices, the LVOF has a tapered center layer (the resonator cavity) in which the thickness changes over its length. Dielectric mirrors are on either side. For a Fabry-Perot type of LVOF, the thickness variation of the cavity layer has to be in order of quarter of the wavelength and very well-controlled, which makes fabrication of miniature LVOF's a technological challenge. This work reports on optical design of a visible LVOF based microspectrometer, IC-Compatible fabrication of LVOF on the top of a 0.35 CMOS chip and optical measurements and characterizations.

Very small taper angles, ranging from 0.001 to 0.1 degree, can be fabricated flexibly in a resist layer by just one lithography step and a subsequent reflow process. The lithography mask is designed based on a geometrical model and FEM simulations of reflow process. The 3D pattern of resist structures are subsequently transferred into SiO2 by appropriate etching. Complete LVOF fabrication involves CMOS-compatible deposition of a lower dielectric mirror using a stack of dielectrics on the wafer, tapered layer formation and deposition of the top dielectric mirror.

The visible LVOF based micro-spectrometer has been designed and fabricated to cover 570 nm to 720 nm wavelength range with a spectral resolution of 1 nm. Spectral resolution can be further improved by appropriate signal processing algorithms.

7680-34, Session 5

Point and stare operation and high-speed image acquisition in real-time hyperspectral imaging

R. D. Driver, D. P. Bannon, D. Ciccone, S. L. Hill, Headwall Photonics Inc. (United States)

The design and optical performance of a small-footprint, low-power, turnkey, Point and Stare hyperspectral analyzer, capable of fully automated field deployment in remote and harsh environments, is described. The unit is packaged for IP67 ingress protection in an air-conditioned enclosure and includes a mechanically ruggedized fully reflective, aberration-corrected hyperspectral VNIR (400-1000 nm) spectrometer with a board-level detector optimized for point and stare operation, an on-board computer capable of full system data-acquisition and control, and a fully functioning internal hyperspectral calibration system for in-situ system spectral calibration and verification. Performance data on the unit under extremes of real-time survey operation and high spatial and high spectral resolution, will be discussed. System stability and system reproducibility in the spatial and spectral domains will be reviewed. Hyperspectral acquisition including full parameter tracking is achieved by the addition of a fiber-optic based downwelling spectral channel for solar illumination tracking during hyperspectral acquisition and the use of other sensors for spatial and directional tracking to pinpoint view location.. For field deployment, the

system is mounted on a Pan and Tilt device, automatically controlled from the analyzer's on-board computer. A hyperspectral macro library has been developed to control hyperspectral image acquisition, system calibration and scene location control. The software allows the system to be operated in a fully automatic mode or under direct operator control through a GigE interface.

7680-35, Poster Session

Wavelength selection for multivariate calibration using Tikhonov regularization

J. M. Ottaway, J. H. Kalivas, Idaho State Univ. (United States); E. Andries, Central New Mexico Community College (United States)

Building a multivariate calibration model to predict spectroscopic properties is typically preformed using one of the following: using all wavelengths (full wavelength method) or a subset of wavelengths (wavelength selection method). The purpose of this poster is to report on a process that combines both full wavelength and wavelength selection schemes into a single approach. Additionally, an in depth comparison is presented for two full wavelength methods (partial least squares (PLS) and Tikhonov regularization (TR) using the two-norm) and three different wavelength selection algorithms used to solve TR using the one-norm. TR using the one-norm was chosen as the wavelength selection approach because it selects wavelengths and builds models simultaneously, making it superior to other wavelength selection approaches such as genetic algorithms or simulated annealing that require lengthy iterative sequential processes of wavelength selection followed by model forming and then testing. When comparing the three approaches (full wavelength, wavelength selection, and both simultaneously) across several spectroscopic data sets, TR using the one-norm consistently produced lower prediction errors. This error reduction however comes at a price: a larger two-norm for the regression vector, and therefore, a potential increase in prediction uncertainty. While the combined approach proved unable to reduce prediction error beyond that of TR using the one-norm, it did reduce prediction error beyond that of PLS and TR using two-norm and also yielded a smaller two-norm than that of TR in one-norm. Results are presented for near infrared, ultraviolet-visible, and atomic emission spectroscopic data sets.

7680-36, Poster Session

Encapsulated thermopile detector array for IR microspectrometer

H. Wu, A. Emadi, G. de Graaf, R. F. Wolffenbuttel, Technische Univ. Delft (Netherlands)

The miniaturized IR spectrometer discussed in this paper comprises slit, planar imaging diffraction grating and Thermo-Electric (TE) detector array and is fabricated using CMOS compatible MEMS technology. The lateral aspect ratio of a TE element is about 18, which is due to the format of the image projected by the grating. Resolving power is maximized by positioning the TE elements as close as possible and is limited by processing constraints. The large aspect ratio also implies a large cross-sectional area between adjacent elements within the array and results in a relatively large heat exchange between micromachined elements in this lateral direction by thermal diffusion. This thermal cross-talk is about 10% in case of a gap spacing of 10 μm between elements. Therefore, the detector array should be packaged (and operated) in the vacuum environment in order to reduce the cross-talk due to the air conduction through the gap. Wafer level packaging is a solution to achieve the detector array in the vacuum environment (1.3mBar) which would reduce the cross-talk to 0.4%. It also offers the advantage of reduced size compared to the device with post processing package after the fabrication. Moreover, the detector array can be fabricated with CMOS compatible in the first stage and later using surface micromachining technology which reduces the process complexity compared to bulk micromachining process. The dimension of the detector array has 7.2 x 0.76 mm2, with an area of each TE element of 650 x 36 μm2 with a 45 μm pitch.

7680-37, Poster Session

Calibration maintenance and transfer with wavelength selection using Tikhonov regularization

M. R. Kunz, J. H. Kalivas, Idaho State Univ. (United States); E. Andries, Central New Mexico Community College (United States) and The Univ. of New Mexico (United States)

Calibration maintenance confronts the problem of models developed in primary conditions predicting samples measured in secondary conditions. Calibration transfer refers to models based on a primary instrument predicting samples measured on secondary instruments. In this poster, near-infrared spectra are used for calibration maintenance and transfer with varying temperatures and instruments, respectively. Tikhonov regularization (TR) is used with spectra from a few samples measured in the secondary conditions/instruments augmented to calibration spectra measured in the primary conditions/instrument to perform calibration maintenance/transfer. To achieve a better predicting regression vector, wavelength selection is used by applying 1-norm and 2-norm penalties on the regression vector to create a 1-norm/2-norm mode of TR. Harmonious (bias/variance trade-off) merits are used in conjunction with variance merits represented by the 1-norm and 2-norm of the regression vector and compared to basic TR with the same augmentation, but only the regression vector 2-norm is used as a variance measure. A new data standardization process is applied to TR in the 1-norm/2-norm mode allowing a least absolute shrinkage and selection operator (LASSO) type algorithm to simplify calculations. Once a regression vector is obtained in the standardized space, the regression vector is transformed back to the original space. Compared to TR in the 2-norm mode, prediction errors for validation samples reduce when TR in the 1-norm/2-norm mode is applied for calibration maintenance and transfer.

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7681-01, Session 1

Functional diffuse reflectance spectroscopy at small source-detector distances based on fast-gated single-photon avalanche diodes

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Diffuse reflectance spectroscopy can probe hemodynamic changes, which are related with brain cortex activity. One of the most important features of time-resolved diffuse reflectance spectroscopy is the intrinsic capability to encode depth information in time-resolved curves; in fact, photons collected at early time investigate only superficial layers, while photons collected at late time carry information also on the deeper ones. It was demonstrated that depth discrimination is independent of source-detector separation and that measurement at small inter-fiber distance should provide higher contrast, and better spatial resolution as compared to longer inter-fiber distances. The most severe obstacle to this kind of measurements is the presence of early photons. In fact, the number of early photons increases dramatically at small inter-fiber distance reducing the dynamic and temporal range achievable. We developed a novel system to perform time-resolved diffuse reflectance at small source detector separation based on a single 200 microns photon avalanche diode (SPAD) operated in fast time gated mode and a broadband fiber laser. By means of time gate it is possible to detect longer lived photons neglecting initial ones. We show results on both homogeneous and inhomogeneous tissue phantoms demonstrating to reach a dynamic range of more than 6 orders of magnitude and a temporal range of more than 4 nanoseconds. Furthermore, this approach proved valuable to detect task related brain activations on volunteers. Finally, we present a mathematical model to describe diffuse reflectance experiment in order to take into account the time-variant behavior of time gated SPAD.

7681-02, Session 1

Counting fluorescent molecules by photon antibunching

H. Ta, Ruprecht-Karls-Univ. Heidelberg (Germany); M. Wahl, PicoQuant GmbH (Germany); D. Herten, Ruprecht-Karls-Univ. Heidelberg (Germany)

Photon-antibunching, i.e. the occurrence of individual photons from a single emitter, is used in single-molecule fluorescence spectroscopy to test whether a single or multiple molecules are observed. Its use for counting the emitting fluorophores was mostly limited to ~3. We present the theoretical framework for extending the range of counting based on the probability distribution for simultaneous detection by four single-photon detectors. Simulations show that the range of counting should go well beyond 20 fluorophores with a moderate error. We also present the successfull implementation of the proposed method by use of a novel single-photon counting card with four parallel detection channels. Using immobilized double-strand DNA oligonucleotides labeled with multiple fluorescent dyes we found that the range of counting can be extended beyond ~10 emitting fluorophores. Currently, we investigate the scope of our novel method for quantifying protein copies in biomolecular complexes.

7681-03, Session 1

High-throughput multichannel time-tagged photon counting

M. Wahl, H. Rahn, T. Roehlicke, PicoQuant GmbH (Germany); G. Kell, Fachhochschule Brandenburg (Germany)

not yet available

7681-05, Session 1

Characterization of photon counting systems at NPL

E. Theocharous, J. Y. Cheung, C. J. Chunnilall, National Physical Lab. (United Kingdom)

The full characterisation of photon counting detection systems is important because it allows the identification and subsequent adoption of the system with the optimum performance. It also allows the uncertainty contributions introduced by that particular detection system to be calculated and used in the estimation of the combined uncertainty of the measurement in which that detection system is being used. The Optical Technologies Division at NPL has assembled dedicated facilities, which are able to characterise the critical operating parameters of photon counting systems anywhere in the wavelength range 250 nm to 2 mm. These include the absolute and relative spectral responsivity over the wavelength range of interest, the spatial uniformity of response at the wavelengths of interest, the deviation from a true linear response as a function of incident radiant power and the stability as a function of time or ageing. In the case of photon counting detector arrays, the pixel to pixel spatial uniformity of response at different wavelengths, the inter-pixel spatial responsivity and the optical cross-talk between neighbouring pixels can also be characterised. Using these facilities, the performance of a number of photon counting systems has been measured in an effort to identify the most appropriate detector technologies for the various radiometric applications NPL is currently addressing. This presentation will describe the dedicated facilities which exist at NPL and will highlight how they are being used to provide traceable measurements of the key performance parameters of photon counting systems. Examples of characterisations of photon counting systems will be presented.

7681-06, Session 2

Three-dimensional passive sensing and imaging with photon counting

B. Javidi, Univ. of Connecticut (United States); M. M. Hayat, S. Narravula, The Univ. of New Mexico (United States)

This invited paper presents an overview of our activities in 3D photon-counting integral imaging for object recognition and visualization of images under photon-starved conditions.

7681-07, Session 2

A technology review of time-of-flight photon counting for advanced remote sensing

R. A. Lamb, SELEX GALILEO (United Kingdom)

Time correlated single photon counting (TCSPC) has made tremendous

progress during the past ten years enabling improved performance in precision time-of-flight rangefinding and LIDAR. In this review the development and performance of several ranging systems is presented that use TCSPC for accurate ranging and range profiling over distances up to 17km. A range resolution of a few millimetres is routinely achieved over distances of several kilometres. These systems include single wavelength devices operating in the visible; multi-wavelength systems covering the visible and near infra-red; the use of electronic gating to reduce in-band solar background and, most recently, operation at high repetition rates without range aliasing- typically 10MHz over several kilometres. These systems operate at very low optical power (<100 W). The technique therefore has potential for eye-safe LIDAR monitoring of the environment and obvious military, security and surveillance sensing applications. The review will highlight the theoretical principles of photon counting, fast digital data acquisition, optical transceiver design and low-power optical sources. Technology trends in TCSPC rangefinding are merging with those of quantum cryptography and its future application to revolutionary quantum imaging provides diverse and exciting research into secure covert sensing, ultra-low power active imaging and quantum rangefinding.

7681-08, Session 2

Anti-aliasing techniques in photon-counting depth imaging using GHz clock rates

N. J. Krichel, A. McCarthy, R. J. Collins, G. S. Buller, Heriot-Watt Univ. (United Kingdom)

We previously presented a photon-counting time-of-flight depth imaging system, designed for the rapid acquisition of three-dimensional target models by steering a single scanning pixel across the field angle of interest. Low average laser powers used in conjunction with time-correlated single-photon detection have resulted in an eye-safe system capable of resolving non-cooperative target surfaces at km ranges. To minimise the per-pixel dwelling times required to obtain sufficient photon statistics for accurate distance resolution, periodic illumination at multi-MHz repetition rates was applied. Careful system design has resulted in depth resolutions of less than 1mm in some cases.

Resolving the absolute target range with a rapid periodic signal is only possible at sufficiently short distances: if the round-trip time towards an object is extended beyond the duration between two optical pulses, the return signal cannot be assigned to an unambiguous range value. Whereas constructing a precise depth image based on relative results may still be possible, the absolute range will not be known with certainty and potentially serious ambiguity issues will also emerge in scenes containing a diverse range of depths.

We describe recent results from our scanning photon-counting depth sensor. We introduce a technique to avoid range ambiguity effects in time-of-flight depth imaging systems at high average pulse rates. A long pseudo-random bitstream is used to trigger the illuminating laser. A cyclic, fast-Fourier supported analysis algorithm is used to search for the pattern within return photon events. We demonstrate this approach at base clock rates of up to 2 GHz with pattern lengths of several Mbit, allowing for unambiguous distances of hundreds of km. Scans at long distances and with large pixel-to-pixel separations are presented. Results acquired with different single-photon detectors are compared in terms of key metrics such as processed photon return, detection efficiency and timing uncertainties.

7681-09, Session 2

Cross strip microchannel plate imaging photon counters with high time resolution

O. H. Siegmund, J. V. Vallerga, A. S. Tremsin, Univ. of California, Berkeley (United States); L. Stonehill, R. Shirey, M. Rabin, Los Alamos National Lab. (United States)

The focus of this paper is on a novel MCP imaging detector scheme using the Cross Strip (XS) anode. This anode uses charge division, and centroiding, of microchannel plate charge signals detected on two orthogonal layers of sense strips to encode event X-Y position, event time and signal amplitude. We are developing XS anode sensors that will, in combination with a new generation of small pore MCP's (less than 6um pores), perform at the highest resolution levels (<10µm) with self triggered <1 ns timing accuracy and encode photons at greater than 5 MHz rates. Our development of the XS anode scheme has been demonstrated with a laboratory detector format of 22mm using a pair of microchannel plates. This demonstrates good spatial resolution (better than 25um FWHM) using low MCP gain (5 x 105). We are also using this concept to subsequently produce sealed tubes with various photocathodes for coverage of a wide range of wavelengths. To encode event positions we have designed, built a number of front end boards with two RD-20, 32 channel preamplifier ASICs. The pre-amplified signal is post-amplified on the same board in order to match the dynamic range of 60 Msps ADCs that constantly digitize the signal for subsequent digital peak detection and FPGA firmware event position calculation. This electronics has allowed us to employ XS anodes with high spatial resolution at event rates of >5 MHz with event timing of <2ns. Such detector system may be a significant enabling technology for several important applications, including airborne and space situational awareness, high-speed adaptive optics, astronomy of transient and time-variable sources, and optical metrology. Versions of our XS designs that can achieve < 100 ps time resolution will also be valuable for three-dimensional imaging, biological single-molecule fluorescence lifetime microscopy, optical and infrared tomography, and hybrid mass spectrometry.

7681-10, Session 3

Photon counting detector for laser time transfer and optical navigation in space

J. Blazej, I. Prochazka, J. Kodet, Czech Technical Univ. in Prague (Czech Republic)

The review of photon counting detectors based missions for the laser time transfer ground to space in Chinese and European programs will be presented. The new self-calibration scheme of detector package will be introduce together with experimental results showing several days ground campaign. The produced data set allows applied post-processing algorithms to enhance final long-term stability of a range signal down to 2 ps over several days. As a near-future outlook, proposed instruments for new missions will be presented. The first one designed for the Galileo program - optical detector for the laser time transfer ground to space. The second one is designed to provide one-way ranging of unprecedented performance: sub-centimeter precision and accuracy may be achieved over distances of several AU. Data products from this instrument will provide an optical reference for distance measurements based on traditional ranging systems, being free from dispersive plasma effects normally encountered in standard RF-based ranging systems. And it also provide a complement radio science observations, by up-link signal time-of-arrival measurements vs. the on-board ultra stable oscillator. It will allow the use of standard TM/TC signals and down-link data transmissions for ranging and radio science purposes, while increasing significantly the observation time and the amount of data available for ranging and radio science. And last but not least it will enable also time transfer capability ground to space.

7681-11, Session 3

Quantum imaging: an application for single-photon detectors

R. W. Boyd, Univ. of Rochester (United States)

Image formation making use of quantum states of light allow dramatic new possibilities in the field of image science. In this contribution, we review some of the conceptual possibilities afforded by quantum imaging and describe some recent work that displays some of these features. Examples include the possibility of imaging with resolution surpassing

the classical Rayleigh limit and the ability to perform "interaction-free" imaging. In addition, we present some new experimental results on the role of coherence and indistinguishability in determining the properties of two-photon interference.

7681-12, Session 4

High-order photon bunching measured with a multi-element superconducting nanowire single-photon detector

M. J. Stevens, B. Baek, National Institute of Standards and Technology (United States); E. A. Dauler, A. J. Kerman, R. J. Molnar, S. A. Hamilton, Lincoln Lab. (United States); K. K. Berggren, Massachussets Institute of Technology (United States); R. P. Mirin, S. W. Nam, National Institute of Standards and Technology (United States)

We demonstrate a new approach to measuring high-order temporal coherences that uses a four-element superconducting nanowire single-photon detector (SNSPD). The four independent, interleaved single-photon-sensitive elements parse a single spatial mode of an optical beam over dimensions smaller than the minimum diffraction-limited spot size, offering an alternative to conventional experimental geometries, in which multiple beamsplitters direct light to several discrete detectors that each sample a replica of the entire mode. We observe high-order photon bunching of a chaotic light source and a high degree of coherence for a laser source, as predicted by theory.

7681-13, Session 4

Superconducting transition-edge sensors optimized for high-efficiency photon-number resolving detectors

A. E. Lita, B. Calkins, L. A. Pellouchoud, National Institute of Standards and Technology (United States); A. J. Miller, Albion College (United States); S. W. Nam, National Institute of Standards and Technology (United States)

Single-photon detectors have gained increased interest in recent years due to the rapid expansion in the fields of quantum optics and quantum information processing. In conjunction, the field of metrology also has seen an interest surge in single-photon detectors due to applications such as qualification of single photon sources and detector calibration. Ideal single photon detectors for quantum information applications should operate at wavelengths that span visible through infrared with very high quantum efficiency, have photon-number-resolving capabilities, high speed, and very low dark-count rates. Currently no single-photon detector technology is able to provide a detector that achieves all the properties that would make such an ideal detector.

Superconducting transition-edge sensors (TESs) however, currently have almost all the required properties, short the high speed operation. TESs are microcalorimeters that have the ability of distinguishing single photons with negligible dark counts. In addition, these superconducting single photon detectors have the ability to unambiguously resolve the photon number in a pulse of light and can be optimized for high quantum efficiency from near-ultraviolet to near-infrared. Detection of visible and near-infrared light at the single-photon level and discrimination between one- and two-photon absorption events place stringent requirements on TES design in terms of heat capacity, thermometry, and optical detection efficiency. TES optimization for high quantum efficiency at particular wavelengths from near-ultraviolet to near-infrared is achieved by designing multilayer device structures that enhance the absorption of light into the active device material. Accurate measurements of optical constants for all materials and fine control over layers thicknesses in the multilayer stack can increase the detector efficiency at values higher than 99%.

We describe our progress on the fabrication and evaluation of our fiber coupled high-efficiency photon-number-resolving detectors.

7681-14, Session 4

Efficient coupling light into nanowire photodetectors

K. K. Berggren, Massachusetts Institute of Technology (United States)

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7681-15, Session 4

Compactly packaged superconducting nanowire single-photon detector with high-detection efficiency

S. Miki, T. Yamashita, W. Qiu, M. Fujiwara, M. Sasaki, Z. Wang, National Institute of Information and Communications Technology (Japan)

We report on the development of compactly packaged superconducting nanowire single photon detectors with an optical cavity (OC-SNSPDs). OC-SNSPD consists of Au mirror, SiO cavity and NbN nanowire on MgO substrate and anti reflection (AR) layer. To achieve efficient coupling, the thickness of MgO substrate was reduced down to 45 mm by mechanical polishing, and installed into compact package blocks. The fiber-end was placed at the backside of substrate so that the distance between the fiber-end and SNSPD device was kept to 65 mm. From the system DE measurement at different substrate thickness and simple estimation of Gaussian beam profile, we can confirm ~98 % of input light beam could irradiated into 15 × 15 mm2 nanowire area from back side of substrate without any lens system. An NbN OC-SNSPD achieved system DE of 9.5 % at 1550 nm and 25 % at 1310 nm wavelength, respectively at dark count rate of 100 c/s.

7681-16, Session 4

Enhanced telecom wavelength sensitivity in NbTiN superconducting nanowire single-photon detectors fabricated on oxidized silicon substrates

R. H. Hadfield, M. Tanner, C. M. Natarajan, Heriot-Watt Univ. (United Kingdom); B. Baek, S. W. Nam, National Institute of Standards and Technology (United States); S. N. Dorenbos, V. Zwiller, Technische Univ. Delft (Netherlands)

Superconducting nanowire single-photon detectors have emerged as a highly promising infrared single-photon detector technology, offering free-running operation with low dark count rates and picosecond timing resolution. New devices, employing NbTiN instead of NbN, have recently been demonstrated. These can be fabricated on oxidised Si substrates, affording more versatility than MgO or sapphire. In this paper, we report on the practical fibre-coupled detection efficiency of these devices in the 900nm-1700 nm spectral range. Owing to reflection at the SiOx/Si interface, these devices exhibit a peak efficiency of 20% at 1300 nm, coupled with low dark count rates (100 Hz) and picosecond timing resolution.

7681-17, Session 4

A superconducting nanowire single-photon detector (SNSPD) system for research at the National Physical Laboratory

C. R. Fitzpatrick, National Physical Lab. (United Kingdom) and Heriot-Watt Univ. (United Kingdom); R. H. Hadfield, Heriot-Watt Univ. (United Kingdom); A. G. Sinclair, National Physical Lab. (United Kingdom); C. M. Natarajan, Heriot-Watt Univ. (United Kingdom)

High-performance single-photon detectors are essential to emerging single-photon technologies such as quantum key distribution (QKD) [1] and quantum optical metrology [2]. Superconducting nanowire single-photon detectors (SNSPDs) [3] are a promising candidate for use at telecom wavelengths, where the sensitivity and timing resolution of semiconductor-based detectors are limited by their material properties. Attractive properties of SNSPDs include low jitter (60 ps), fast reset time (~10 ns) and low dark counts. Fiber-coupled efficiencies of ~1% at 1550 nm are routinely achieved for simple NbN wire meander at dark count levels below 100 Hz [4]. Greatly improved efficiencies have been achieved integrating SNSPDs with optical cavities [5].

In this paper we report on the construction and characterization of a two channel SNSPD system for the National Physical Laboratory (NPL), UK. The system design is based on a Gifford-MacMahon cryocooler; as such, no cryogen handling is required to reach the 3K operating temperature [6]. Two nanowire chips containing a 50% fill factor 10um x 10um NbN meander on a MgO substrate are fibre-coupled and mounted inside a vacuum chamber. A room temperature amplifier chain enables the output pulse to be processed with single-photon counting electronics.

This detector system will extend the range of NPL's single-photon detection capabilities into the useful telecoms band, enabling a range of experiments relevant to the fields of Quantum Information Processing and quantum-optical metrology. Plans include making g(2)( ) measurements of single-photon sources at 1310nm, using correlated photons to measure the quantum efficiency of the SNSPD and standardization of the Quantum candela.

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7681-18, Session 5

Room-temperature single-photon sources: design, performance, and applications

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Single photon sources are key devices for optical quantum information processing, miniaturized optical elements, as well as light standards. Several physical systems have been exploited to generate on-demand or heralded single photons. Examples are semiconductor quantum dots, defect centers in diamond, alkali atoms, and parametric down-conversion sources.

In this contribution I will review these sources and highlight their unique properties and pecularities with respect to applications in quantum information processing. Issues regarding triggering and detection of photons will be discussed as well.

A special focus lies on room temperature sources. I will discuss a compact design for a single photon source based on nitrogen-vacency (NV) centers in diamond. The goal of the design is to realize a robust non-classical light standard. Furthermore, a narrow-band heralded photon source based on intra-cavity parametric down-conversion will

be introduced. Photons from these sources are matched to atomic resonances and are thus ideally suited to transfer quantum bits and entanglement.

7681-19, Session 5

Twin photons generation in photonic crystal nanostructures

F. A. Bovino, Elsag Datamat S.p.A. (Italy); M. Braccini, M. Centini, C. Sibilia, M. Bertolotti, Univ. degli Studi di Roma La Sapienza (Italy)

Quantum information processing has progressively become a concrete reality. This led to the need of developing twin photons high efficiency integrated sources.

Several techniques have been proposed in order to obtain twin photons by Spontaneous Parametric Down Conversion and enhance the intrinsic low efficiency of this process. Among them, counterpropagative scheme grants an a priori separation of the photon pairs, leading to a more efficient collection.

A suitable structure ensuring this features - high efficiency, on chip nanostructured device - can be a micro-cavity obtained in a based planar dielectric waveguide. The cavity was introduced with the intent of having the pump field to be resonant, and thus to be localized and amplified in order to enhance the nonlinear interaction .

This sort of device takes advantage of a counterpropagative scheme for the generated photon pairs, which propagate as guided modes in opposite directions and transversely with respect to the pump field. Differently from other solutions, here we have a pump which propagates in the structure as a waveguide's mode, increasing the integrability of the device.

Since the correlation of the downconverted photons is connected to the bandwidth of the generated fields, is important to reach narrow bandwidths, a goal that can be obtained by means of a second resonant cavity, transverse with respect to the former.

A mathematical model for the SPDC in the waveguide is presented and numerical simulation is discussed along with the conclusions.

7681-20, Session 6

Simulations of avalanche breakdown statistics: probability and timing

J. S. Ng, C. H. Tan, J. P. R. David, The Univ. of Sheffield (United Kingdom)

Semiconductor avalanche photodiodes biased above their breakdown voltages are used in photon counting applications, giving rise to the term Single Photon Avalanche Diodes (SPADs). With a combination of different models (recurrence equations and Random Path Length Model), important avalanche breakdown statistics, such as avalanche breakdown probability, dark count rate, and the distribution of time taken to reach breakdown (providing mean time to breakdown and jitter), can be simulated. These simulations enable unambiguous studies on effects of material choice, avalanche region width, and carrier dead space on the avalanche statistics, which are the fundamental limits of the SPADs. This paper presents findings from these simulations and then explains their relevance to designs of SPADs. Some of the findings are as follows. Due to competing effects between dead spaces, which are significant in modern SPADs with narrow avalanche regions, and converging ionization coefficients, the breakdown probability versus overbias characteristics from difference avalanche region widths are fairly close to each other. Concerning avalanche breakdown timing, using avalanche material with similar ionization coefficients yields fast avalanche breakdowns with small timing jitter, compared to material with dissimilar ionization coefficients. This is unfortunately the opposite requirement for abrupt breakdown probability versus overbias characteristics. In addition, by taking band-to-band tunnelling current (dark carriers) into account, limits

of avalanche region width for successful SPADs for the materials of InP and InAlAs were established.

7681-21, Session 6

Photon-timing jitter dependence on the injection position in single-photon avalanche diodes

M. Assanelli, A. Ingargiola, I. Rech, M. Ghioni, S. D. Cova, Politecnico di Milano (Italy)

In recent years a growing number of applications demand better and better timing resolution for Single Photon Avalanche Diodes. The challenge is pursuing the improved timing resolution without impairing the other device characteristics such as quantum efficiency and dark counts. This task requires a clear understanding of the physical mechanisms useful to drive the device engineering process.

Studies performed on past generation silicon SPAD devices stated that the main contribution to the photon timing jitter should be ascribed to the statistics of avalanche injection position. However, experimental evidences show that this assumption is not valid in recent devices that have been engineered in order to meet dark count rate and quantum efficiency requirements. Therefore the need arises to re-assess the photon-timing jitter origin starting from a complete experimental characterization of the phenomenon.

We indeed developed an experimental setup in order to characterize the photon-timing jitter as a function of the injection position by means of TCSPC measurements with a laser focused on the device active area. Results not only confirmed that the injection position is not the main contribution to the photon-timing jitter but also evidenced a radial dependence never observed before.

Furthermore, we studied the avalanche current density distribution in the device active area by imaging the photo-luminescence due to hot-carrier emission. Measurements reveal that the emission intensity pattern, and therefore the current density, is spatially non-uniform. We demonstrated also that the photon-emission pattern exhibits a significant correlation with the position-dependent photon-timing jitter.

7681-22, Session 6

Planar silicon SPADs with improved photon detection efficiency

A. Gulinatti, F. Panzeri, I. Rech, Politecnico di Milano (Italy); P. Maccagnani, IMM-CNR sezione di Bologna (Italy); M. Ghioni, S. D. Cova, Politecnico di Milano (Italy) and Micro-Photon-Devices (Italy)

Remarkable advances in semiconductor technology as long as improvements in device design resulted in today's Silicon Single Photon Avalanche Diodes (SPADs) that are widely used in many demanding applications thanks to their excellent performance. However a lot of work is still be done in order to simultaneously meet three requirements crucial in a large number of applications, i.e. high Photon Detection Efficiency (PDE), good timing resolution and suitability for the fabrication of arrays. Currently available devices can be essentially divided in two categories: thin and thick SPADs. While the formers are characterized by an excellent timing resolution (<35ps), the reduced thickness of the absorption layer strongly limits their PDE for wavelengths higher than 800nm. Conversely, thick SPADs achieve good PDE even in the near infrared range, but at the expense of a severe worsening in timing resolution. Moreover, their fabrication technology is inherently non-planar, impairing the fabrication of arrays of detectors.

In this paper we will report on our advances on the design and fabrication of a new planar SPAD capable of overcome the limitations outlined above. While a 10μm thick epitaxial layer allows for the absorption of a significant fraction of photons even at the longer wavelengths, a proper electric field design limits the breakdown voltage value and the timing

jitter; biased guard rings are also included to prevent edge breakdown. Preliminary results show that the new devices can attain a PDE as high as 30% at a wavelength of 800nm, while keeping photon detection jitter below 100ps.

7681-23, Session 7

Progress toward photon counting between 1μm and 1.6μm using silicon with infrared absorbers

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Silicon based avalanche photodiodes (APDs) have exhibited impressive performance over the visible spectrum for more than a decade. Photon counting with these devices has progressed to the level where room-temperature operation and low dark count rates (<100Hz) are commonplace. Several commercial enterprises have been established to capitalise on these devices and many niche markets are now serviced by incorporating these devices into suitable systems. This paper describes one approach that allows the performance of silicon based Geiger-mode avalanche photodiodes (GM-APDs) to be extended into the near-infrared. The process development is described whereby Ge absorbers are incorporated into adapted silicon APD designs to provide separate absorption and multiplication devices. Simulation results are presented outlining the performance of these devices at wavelengths between 1μm and 1.6μm.

The performance results from the adapted silicon APD designs are presented for visible wavelengths. The silicon-germanium bonding process is described and the challenges presented in developing the hybrid absorber/multiplier structure are detailed. Several device architectures are presented to serve applications ranging from LIDAR to adaptive optics, medical imaging to quantum cryptography. Finally some preliminary work on the design of appropriate custom application integrated circuits for these applications is discussed.

7681-24, Session 7

An investigation of single-photon avalanche diode array for biomedical imaging fabricated in a standard low-voltage 0.18-μm CMOS technology

S. Isaak, H. Ian, The Univ. of Nottingham (United Kingdom)

The design, fabrication, characterization and sensitivity performance of multi- array silicon single photon avalanche diode (SPAD) camera for biomedical imaging was integrated in a 0.18μm CMOS technology is presented. The SPADs with diameter of 10μm are implemented as planar p-n junctions and are operated in Geiger mode where the reverse bias voltage (VOP) applied is above breakdown voltage (VBD). A low doping p-well guard ring is used to suppress premature breakdown. The multi-array SPADs camera is an array of 16x1 active pixels that synchronously detect the arrival of photons in nanoseconds. An active pixel containing a SPAD combined with an active quenching circuit and a novel readout channel with a pitch of 22x93 μm2. A number of electro-optical characterizations for the 16x1 SPAD pixel cameras have been performed at room temperature. The dead time is measured as 40 ns and in a good agreement with the simulation results. A multichannel counter has been implemented on FPGA to count the digital pulses detected on 16 channels simultaneously in a given integration time. The apparent detection probability of 21% for =450 nm and at 0.9 V above breakdown voltage. These results highlight that the standard low voltage CMOS SPAD has a good applications in low light level imaging system and comparable to that SPADs performance fabricated in high voltage CMOS technology. The pixel array as a light-sensing device can also be used to acquire the intensity map of scene.

7681-25, Session 7

Hybridization process for back-illuminated silicon Geiger-mode avalanche photodiode arrays

D. R. Schuette, R. C. Westhoff, A. H. Loomis, D. J. Young, J. S. Ciampi, B. F. Aull, R. K. Reich, Lincoln Lab. (United States)

We present a unique hybridization process that permits high-performance back-illuminated silicon Geiger-mode avalanche photodiodes (GM-APDs) to be bonded to custom CMOS integrated circuit readouts (ROICs) - a hybridization approach that allows independent optimization of the GM-APD arrays and the ROICs. The process includes oxide bonding of silicon GM-APD arrays to a transparent support substrate followed by indium bump bonding of this layer to a signal-processing ROIC. This hybrid detector approach enables high-fill-factor pixels with enhanced quantum efficiency in the near infrared as well as large-pixel-count small-pixel-pitch arrays with pixel-level signal processing. In addition, the oxide bonding is compatible with high-temperature processing steps that can be used to lower dark current and improve optical response in the ultraviolet. Results from integrated sensors (e.g. ladar detectors and adaptive-optics wave-front-sensing quad cells) using this technology will be presented.

7681-26, Session 7

Antimonide-based Geiger-mode avalanche photodiodes for SWIR and MWIR photon counting

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At MIT Lincoln Laboratory, avalanche photodiodes (APDs) have been developed for both 2-micron and 3.4-micron detection using the antimonide material system. These bulk, lattice-matched detectors operate in Geiger mode at temperatures up to 160 K. The 2-micron APDs use a separate-absorber-multiplier design with an InGaAsSb absorber and electron-initiated avalanching in the multiplier. These APDs have exhibited normalized avalanche probability (product of avalanche probability and photo-carrier-injection probability) of 0.4 and dark count rates of ~150 kHz at 77 K for a 30-micron-diameter device. A 1000-element imaging array of the 2-micron detectors has been demonstrated, which operate in a 5 kg dewar with an integrated Stirling-cycle cooler. The APD array is interfaced with a CMOS readout circuit, which provides photon time-of-arrival information for each pixel, allowing the focal plane array to be used in a photon-counting laser radar system. The 3.4-micron APDs use an InAsSb absorber and hole-initiated avalanching and have shown dark count rates of ~500 kHz at 77K but normalized avalanche probability of < 1%. Research is ongoing to determine the cause of the low avalanche probability and improve the device performance.

7681-27, Session 8

InGaAs/InP SPADs for near-infrared applications: device operating conditions and dedicated electronics

A. Tosi, A. Dalla Mora, Politecnico di Milano (Italy); S. Tisa, Micro Photon Devices S.r.l. (Italy); F. Acerbi, F. Zappa, S. D. Cova, Politecnico di Milano (Italy)

InGaAs/InP Single-Photon Avalanche Diodes (SPADs) have recently shown good performance in terms of dark count rate and detection efficiency, making them suitable for many applications where it is needed to detect single photons in the 1 - 1.7 µm wavelength range. However, in order to fully exploit such detectors, it is mandatory to operate InGaAs/InP SPADs in optimized working conditions and in association with proper dedicated electronics.

As a matter of fact, different applications may require different working conditions of the SPAD, depending on the photon source characteristics (CW, pulsed or amplitude modulated), the incoming photon rate, the measurement time, etc. Therefore, it is of the utmost importance to completely characterize primary dark count rate, afterpulsing, detection efficiency and timing jitter at different temperatures, excess bias voltages, gate frequencies, gate-on windows, etc, in order to be able to tailor the working conditions to the specific request.

Moreover, in order to reduce afterpulsing and minimize the timing jitter, not only a good device is needed, but also a dedicated electronic circuitry must be employed. Very fast quenching circuits can efficiently reduce the amount of charge carriers flowing through the device, thus minimizing the afterpulsing effect, while low-jitter front-end circuits detect the avalanche pulse with high timing precision thanks to low threshold voltage and differential sensing. Additionally, ancillary electronics (for generating the gate window, counting the avalanche pulses, setting the operating conditions, etc.) further exploits the use of InGaAs/InP SPADs in many more applications.

7681-28, Session 8

High-performance InGaAs/InP-based single-photon avalanche diode with reduced afterpulsing

C. Hu, X. Zheng, J. C. Campbell, Univ. of Virginia (United States); B. M. Onat, X. Jiang, M. A. Itzler, Princeton Lightwave, Inc. (United States)

The passive quenching with active reset (PQAR) circuit has been shown to reduce afterpulsing by limiting the total capacitance that is discharged in passive quenching. This, in turn, reduces the total charge flow during an avalanche event. In order to reduce the stray capacitance, an InGaAs/InP single photon avalanche diode (SPAD) was combined with two GaAs FETs on a sapphire/ceramic submount by wire-bonding. The gated-PQAR circuit has demonstrated a significant reduction of afterpulsing. In the experiment, the photon detection efficiency (PDE) and dark count probability (DCP) were measured at a gate repetition rate of 1 MHz owing to the maximum operating frequency of the pulsed laser driver. To measure the afterpulsing probability, a two-pulse measurement technique was utilized. The light intensity in the first pulse was sufficient to guarantee 100% avalanche probability. Afterpulsing probability was measured in the second pulse. The afterpulsing probability was measured for various delays between the two pulses. At 280K, 1% afterpulsing probability for 10 ns delay was achieved with 12% PDE and 3E–5 DCP. For the same delay at 230K, 30% PDE and 1E–5 DCP was achieved with 6% afterpulsing probability.

7681-29, Session 8

Geiger-mode single-photon counting avalanche photodiodes operating near 0°C

P. Yuan, R. Sudharsanan, X. Bai, J. C. Boisvert, P. A. McDonald, J. J. Chang, W. D. Hong, Spectrolab, Inc. (United States)

The recent development of large format Geiger-mode avalanche photodiode arrays operating in the short wavelength infrared (SWIR) region makes the LAser Detection and Ranging (LADAR) imaging feasible under low light-level conditions for many military applications. In most cases, especially airborne and robotic applications, power consumption is critical to the system design and integration. The Thermo-Electric Cooler (TEC) which controls the sensor temperature is a significant contributor to overall power consumption. A higher sensor operating

temperature will effectively reduce the power consumption of the focal plane array (FPA). With a fine-tuned APD structure, Spectrolab has achieved a dark count rate as low as <10 kHz at 0oC with a 4V overbias. At the meeting we will discuss more device and array performance at this relatively high operating temperature.

7681-30, Session 8

Bias-dependant jitter of InGaAs(P) single-photon detectors

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High timing precision for single photon arrival events is a critical performance metric for many photon counting detector applications, sometimes even surpassing high detection efficiency and low dark count rate in importance.

Low single photon detection jitter (SPDJ) is important for our interplanetary optical communications systems. Furthermore, these interplanetary optical communications systems can also be excellent platforms for testing relativistic gravity and probing physics beyond the Standard Model, and those experiments can have even more stringent requirements on timing precision.

SPDJ can be a strong function of detector bias conditions as well as the spatial position of the photon absorption in the detector. We have characterized both Geiger mode and negative-avalanche feedback (NAF) InGaAs(P) single photon detectors for single photon timing jitter at both 1.06 and 1.5 microns at temperatures ranging from 298K to below 200K. Using pulse-picked mode-locked laser sources, we attenuate the beam greatly to ensure that we are measuring true single photon jitter, not a multi-photon response. We shall present measurement results of SPDJ for InGaAs(P) single photon detectors from several manufacturers and discuss the impact of SPDJ on optical communications performance and possible tests for new physics via optical ranging.

7681-04, Session 9

Iqueye: a single-photon counting very high-speed photometer for the ESO 3.5m NTT

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Iqueye is a single photon counting very high speed photometer built for the ESO 3.5m New Technology Telescope (NTT) in La Silla (Chile) as prototype of a 'quantum' photometer for the 42m European Extremely Large Telescope (E-ELT). The optics of Iqueye splits the telescope pupil into four portions, each feeding a Single Photon Avalanche Diode (SPAD) operated in Geiger mode. The SPADs sensitive area has a diameter of 100 μm, with a quantum efficiency better than 55% at 500nm, and a dark count less than 50 Hz. The quenching circuit and temperature control are integrated in each module. A time-to-digital converter (TDC) board, controlled by a Rubidium oscillator plus a GPS receiver, time tags the pulses from the 4 channels. The individual times are stored in a 2 TeraByte memory. Iqueye can run continuously for hours, handling count rates up to 8MHz, with a final accuracy of each time tag better that 0.5 ns. A first very successful run was performed in Jan 2009; both very faint and very bright stars were observed, demonstrating the high photometric quality of the instrument. The first run allowed also to identify some opto-mechanical improvements, which have been implemented for a second run performed in Dec 2009. The present paper will describe those improvements and the obtained astronomical results.

7681-31, Session 9

Single-photon detectors based on InP avalanche diodes: status and prospects

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Lightwave, Inc. (United States)

Single photon detectors based on avalanche diode structures are frequently the best choice for applications requiring high performance, high reliability, ease of implementation, and scalability. In the past several years, we have made significant progress for certain properties of InP-based single photon avalanche diodes (SPADs). For instance, the fundamental tradeoff between photon detection efficiency (PDE) and dark count rate (DCR) for InP/InGaAs SPADs designed for 1.55 μm photon detection has been managed so that for PDE ~ 20%, devices routinely exhibit DCR values of a few kHz, and "hero" devices demonstrate that it is possible to achieve sub-kHz DCR performance at temperatures readily accessible using thermoelectric coolers. High precision timing jitter has also been demonstrated for these detectors, with 100 ps jitter found for typical operating conditions, and 50 ps or less obtained for sufficiently high excess bias. However, important limitations remain, particularly with respect to maximum count rates. Although intrinsic SPAD response is fast, with avalanche build-up occuring in less than 1 ns, afterpulsing effects have often limited counting rates to the range of 1 to 10 MHz. Among the strategies that have been adopted recently to circumvent some of these present limitations, new monolithic chip-level concepts for obtaining improved performance through avalanche self-quenching are promising, and we will present recent results from devices with monolithically integrated quench resistors. Finally, to further assess the future prospects for InP SPAD performance, we present a comparison with Si-based SPADs.

7681-32, Session 9

Modeling negative feedback in single-photon avalanche diodes

M. M. Hayat, D. A. Ramirez, The Univ. of New Mexico (United States); G. J. Reez, The Univ. of Sheffield (United Kingdom); M. A. Itzler, Princeton Lightwave, Inc. (United States)

Recently, considerable attention has been placed upon exploiting the negative-feedback effect in accelerating the quenching time of the avalanche current in passively quenched single-photon avalanche-diode (SPAD) circuits. Reducing the quenching time results in a reduction in the total charge generated in the SPAD, thereby reducing the number of trapped carries; this, in turn, can lead to improved after-pulsing characteristics. In a simple passively quenched SPAD circuit, a photon triggers an avalanche breakdown causing current to flow through the diode and a load resistor. The voltage build-up across the load resistor reduces the bias across the SPAD, thereby weakening the impact ionization process. Consequently, a drop in the current flow occurs in the SPAD leading to a reduction of the voltage across the load resistor. However, this negative feedback is not instantaneous but delayed due to RC-effects and other physical factors. After a delay, the voltage is restored once again across the SPAD by means of the DC source and the avalanche current increases once again. This cycle continues until the stochastic avalanche current quenches with a certain probability. In this paper we review recent analytical (stochastic and deterministic) and Monte-Carlo based models for the evolution of the avalanche current in passively quenched SPAD circuits. The quenching time is investigated and the simulation results are compared to experimental data obtained from SPADs exhibiting the negative feedback effect.

7681-33, Session 9

High-gain and low-excess noise near-infrared single-photon avalanche detector arrays

K. R. Linga, Amplification Technologies, Inc. (United States)

We have designed and developed a new family of photodetectors and arrays with Internal Discrete Amplification (IDA) mechanism for the realization of very high gain and low excess noise factor in the visible and near infrared spectral regions. These photodetectors can operate in linear detection mode with gain-bandwidth product in excess of 4X1014.

Potential benefits of this technology over conventional avalanche photodetectors include ultra low excess noise factor, very high gain, lower reset time (< 200 ns). In the photon counting mode, the devices can be operated in the non-gated mode under a constant dc bias. Because of its unique characteristics of self-quenching and self-recovery, no external quenching circuit is needed. This unique feature of self quenching and self-recovery makes it simple to less complex readout integrated circuit to realize large format detector arrays.

In this paper, we present the discrete amplification design approach used for the development of self reset, high gain photodetector arrays in the near infrared wavelength region. We present the simulation results as well as the measured performance results. The demonstrated device performance far exceeds any available solid state Photodetectors in the near infrared wavelength range. These devices are ideal for researchers in the field of spectroscopy, industrial and scientific instrumentation, Ladar, quantum cryptography, night vision and other military, defence and aerospace applications.

7681-34, Session 9

Comparison of linear-mode avalanche photodiode lidar receivers for use at one-micron wavelength

M. A. Krainak, X. Sun, G. Yang, W. Lu, NASA Goddard Space Flight Ctr. (United States)

Silicon avalanche photodiode (APD) detectors have been used in most space lidar receivers to date with a sensitivity that is typically hundreds of photons per pulse at 1064 nm, and is limited by the quantum efficiency, APD gain noise, dark current, and preamplifier noise. We have purchased and tested InGaAs avalanche photodiode based receivers from several US vendors as possible alternatives. We present our measurement results and a comparison of their performance to our baseline silicon APD.

Using a multichannel scalar instrument, we observed undesired dark counts and afterpulsing in some devices, even though the APDs were biased below the breakdown voltage. These effects are typically associated with over-biased Geiger-mode photon-counting, but we demonstrate that the probability distribution indicates their necessity at the high gains typically associated with operation slightly below the breakdown voltage.

We measured the following parameters for our 0.8 mm diameter baseline silicon APD receiver: excess noise factor 2.5, bandwidth 210 MHz, minimum detectable pulse (10 ns) in incident photons 110 photons, noise equivalent power 50 fW/rt-Hz. We will present our test procedures and results for the InGaAs based APD receivers.

7681-35, Session 9

2.23 GHz photon counting based on InGaAs/InP single-photon avalanche photodiode for quantum key distribution

J. Zhang, C. Barreiro, P. Eraerds, R. T. Thew, H. Zbinden, Univ. of Geneva (Switzerland)

We implement an InGaAs/InP single-photon avalanche photodiode (SPAD) for photon counting with the fastest gating frequency reported so far, of 2.23 GHz, which approaches the frequency response limit of the SPAD. We characterize the afterpulsing distribution in time. We model and simulate the rapid gating SPAD for coherent one-way quantum key distribution, in which Mega bps key rates are achieved for the distances less than 40 km with 50 ns deadtime and the maximum distance are limited to ~170 km with 1 ms deadtime.

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7682-01, Session 1

Chemical sensors based on the extraordinary optical transmission (EOT) and their application to antibody screening

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Nanohole arrays milled in thin films of noble metal show an increase of light transmission at certain wavelengths. This phenomenon is called extraordinary optical transmission, and is due to the excitation of surface plasmons (SPs) by grating coupling. The conditions for surface plasmon resonance (SPR) depend on the dielectric constant at the interface. The adsorption of molecular species then shifts the resonance condition forming the principle for the SP-based sensors. In this work, we will report on our progress to the development of an integrated microfluidic system containing nanohole arrays as sensor elements. These devices are being used to detect specific antibody - antigen interactions. The implementation of multiplex detection has allowed the simultaneous determination of several antibody - antigen pairs. The device has been calibrated for a particular antibody and its analytical figure of merits has been determined. Finally, real time investigation of the binding kinetics will also be presented.

7682-02, Session 1

Photonic materials for encoding and detection of biomolecules

Z. Gu, Southeast Univ. (China)

High-throughput or multiplexed detection of molecules with high sensitivity and specificity is of great importance in gene profiling, clinical diagnostics, and environmental monitoring. One of the key techniques for realization these aim is the identification of different binding events in parallel. In this context, suspended carriers have been drawing more and more attention. Among these carriers, fluorescent dyes are the main encoding elements, and the beads encoded by fluorescence have been commercialized. Recently, self-assembled photonic materials appeal themselves as new fluidic encoding carriers for multiplex or high-throughput bioassays. The codes of the self-assembled carriers are the characteristic reflection peaks originated from their stop-band. Photonic beads with different reflection peak position could be controlled by changing the diameter of composing nanoparticles. To further extend the capacity of code, biologically active semiconductor quantum dots (QDs) were incorporated to the encoded photonic beads. When introduced the inverted structure of self-assembled materials, the encoding carriers could be used for label-free detection. We anticipated that the photonic materials may open new opportunities in gene expression studies, high-throughput screening, and medical diagnostics.

7682-03, Session 1

Photonic crystal fibers for plasmon-assisted bio- and chemical-sensing, overview of the design, fabrication, and applications from visible to THz

M. A. Skorobogatiy, Ecole Polytechnique de Montréal (Canada)

The concept of photonic crystal fiber-based surface plasmon resonance

sensor operating with low refractive index analytes is developed. Plasmon wave on a surface of a metal feature embedded into a fiber microstructure is excited by the fundamental core mode of a fiber. We demonstrate that by judicious design of a photonic crystal reflector, effective refractive index of a core mode can be made considerably smaller than that of a core material, thus enabling efficient phase matching with a plasmon, high sensitivity, and high coupling efficiency from an external Gaussian source, at any wavelength of choice from the visible to THz. We discuss recent progress in fabrication of such metal containing structures including metal coated Bragg fibers and microstructured fibers, highly porous THz fibers with ferroelectric layers, as well as micro- and nano-wire arrays embedded into dielectrics. Potential sensitivities and modes of operation of such sensors for bio- and chemical sensor applications are discussed.

7682-04, Session 2

In-fiber devices and sensors based on air-silica microstructured optical fibers

W. Jin, The Hong Kong Polytechnic Univ. (Hong Kong, China)

This paper reports some of our recent work on microstructrued optical fiber devices and sensors, including strong long period gratings made on both index-guiding PCFs and air-core photonic bandgap fibers.

7682-05, Session 2

Ultra-compact fiber grating lasers for sensing applications

B. Guan, Jinan Univ. (China); Y. Zhang, Dalian Univ. of Technology (China); H. Tam, The Hong Kong Polytechnic Univ. (China)

Fiber grating laser sensors have been attracting interest because of their high signal-to-noise ratio and narrow linewidth that permit high resolution sensing. Distributed feedback (DFB) and distributed Bragg reflector (DBR) are two structures that have been widely investigated as fiber grating laser sensors. Advantages of DFB fiber laser are that it offers robust single mode operation and high resilience to environmental perturbations. However, DFB fiber laser is typical ~ 5 cm in length, which is too long for applications requiring point sensors. DBR fiber laser can be made shorter. To date, 2-3 cm long DBR fiber lasers have been achieved. It is still too long for applications requiring high spatial resolution sensors. Furthermore, the long cavity length results in longitude mode spacing much smaller than the grating reflection bandwidth, so the laser is susceptible to mode hopping if it is subjected to external perturbations such as temperature or strain gradients. This significantly limits the practical applications of DBR fiber laser.

In this paper, we report the fabrication and characterization of ultra-compact DBR fiber lasers. The fiber lasers with total length less than 1 cm were fabricated in both Er-doped fiber and Er/Yb co-doped fiber by inscribing Bragg gratings in the active fibers with 193 nm excimer laser without hydrogen loading. The lasers have longitude mode spacing comparable to the grating bandwidth, so the cavity supports only one longitude mode within the grating bandwidth. This obviates the possibility of mode hopping when the lasers are subjected to any external perturbations.

7682-06, Session 2

Characteristics and application of phase-shifted long-period fiber grating fabricated by CO2 laser

H. Duan, X. Lan, T. Wei, Y. Zhang, H. Xiao, Missouri Univ. of Science and Technology (United States)

Abstract

In this paper, we report fabrication of phase shifted long-period fiber gratings (PS-LPFG) using point-by-point CO2 laser irradiation and the application of them to multi-parameter sensing. Two types of PS-LPFGs are studied, including the conventional two-section PS-LPFG made by separating two identical LPFGs with a small distance and the new three-section PS-LPFG by introducing certain phase shifts into three cascaded LPFGs. The sensing mechanisms of these PS-LPFGs are studied. The spectral characteristics of the PS-LPFGs are studied as a function of the amount of phase shifts. Their responses to temperature and refractive index are characterized experimentally. The thermal stability and temperature-compensation capability of these gratings are investigated experimentally by long-term exposure to high temperatures. With two or three identical gratings, the PS-LPFG has shown unique advantages over the conventional LPFG for sensing applications, such as temperature-compensation capability, higher sensitivity for refractive index measurement, and improved long-term thermal stability.

7682-07, Session 3

Single-Virion sensing and nanoparticle trapping with optical microcavities

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Viral infections are a major cause for human disease and have the potential to spread rapidly through populations across the globe. Early detection of virions is of added urgency in order to prevent a wider outbreak and to improve medical diagnosis and treatment. Rapid virus detection requires a biosensor that ideally responds to a single virus binding event. We demonstrate an optical technique that provides such ultimate sensitivity for detection of label-free virions. Virus and other nanoparticles are detected from resonance wavelength fluctuations in high-Q microcavities where single binding events are discerned from discrete changes in resonance wavelength. Furthermore, individual nanoparticles in aqueous solution are observed to be attracted to and orbit within the evanescent sensing ring of a Whispering Gallery Mode micro-sensor with only microwatts of driving power. This Carousel trap, caused by attractive optical gradient forces, interfacial interactions, and the circulating momentum flux, considerably enhances the rate of transport to the sensing region, thereby overcoming limitations posed by diffusion on such small area detectors. Resonance frequency fluctuations, caused by the radial Brownian motion of the nanoparticle, reveal the radial trapping potential and the nanoparticle size. Since the attractive forces draw particles to the highest evanescent intensity at the surface, binding steps are found to be uniform.

7682-08, Session 3

Detection of HER2 breast cancer biomarker using the opto-fluidic ring resonator biosensor

J. T. Gohring, Univ. of Missouri School of Medicine (United States); X. Fan, Univ. of Michigan (United States); P. S. Dale, Univ. of Missouri School of Medicine (United States)

In this work, we describe a novel approach for detecting the HER2/neu extra-cellular domain (ECD) protein in human serum samples using the opto-fluidic ring resonator (OFRR). OFRR sensing technology incorporates microfluidics and optical sensing methods to achieve rapid label free detection in a small and low cost platform. In this study, HER2 proteins were spiked in PBS running buffer and serum at varying concentrations. Concentrations of the HER2 protein were adjusted in serum to levels typical of breast cancer patients that show over-expression of this particular beast cancer biomarker. The OFRR was modified with a biologically functional layer to efficiently capture the HER2 biomarker and produce a sensing signal through interaction with the evanescent field of the optical resonator. Results show effective capture of HER2 at medically relevant concentrations in serum and was achieved for concentrations as low as 13ng/mL and ranged to above 100 ng/mL. This work will lead to a device that can be used as a tool for monitoring disease progression in a low cost sensing setup.

7682-09, Session 3

Optical detection of nanoparticles by mode splitting in whispering gallery mode microcavities

J. Zhu, S. K. Özdemir, L. He, D. Chen, L. Yang, Washington Univ. in St. Louis (United States)

As the interests in nanoparticle applications and awareness of their potential risks to health and environment are increasing, there is a great need to develop new label-free optical techniques, which allow portable, inexpensive and high-resolution devices capable of real-time and in-situ detection of single particles. Optical microcavities with high quality factors (Q) and tight mode volumes have shown their potentials in various sensor applications. Single nanoparticle/molecule detection by whispering-gallery-mode (WGM) resonance shift or linewidth variation has been achieved using microspheres and microtoroids. Yet a stronger interaction between the sensing object and the microcavity will result in the splitting of WGM, which can serve as an efficient sensing tool.

Here we experimentally demonstrate WGM splitting induced by a single nanoparticle adsorbed on an ultra-high quality factor (UHQ) microtoroid. The UHQ and tight field confinement of the cavity field allow enhanced/extended interaction with the particles providing an enormous enhancement in the detection sensitivity and resolution with a very small laser input power (~ 10 microwatt). Ultra-sensitive detection of both standard polystyrene nanospheres and homemade potassium chloride (KCL) nanoparticles were investigated. We achieved real-time detection of nanoparticles as small as 30 nm in radius in air. Experimental results and the underlying physics are well-explained using 2D and 3D finite element simulations. Our theoretical calculations suggest that particle detection down to a few nanometers is possible using our technique.

7682-10, Session 4

On-chip single nanoparticle detection using ultra-high-Q whispering gallery microresonator

L. Yang, J. Zhu, S. K. Özdemir, L. He, Y. Xiao, L. Li, D. Chen, Washington Univ. in St. Louis (United States)

Over the last decade, various nanoparticles have been synthesized for many applications in areas from biomedical diagnostics and therapeutics to optoelectronics and sensors. At the same time, massive quantities of nanoparticles continuously generated as end/by products of industrial processes have become sources of exposure posing risks to humans and environment health. It is of great importance to develop a real-time detection tool with single nano-particle resolution to understand the fundamental mechanism of particle formation and dynamic particle-environment interactions. We investigate a novel technique, mode-splitting in a monolithic ultra-high-Q whispering-gallery-mode (WGM) microresonator, for real-time and in-situ detection of single nanoparticles. The mode-splitting technique for ultra-sensitive particle sensing

stems from the lifted degeneracy of WGMs by enhanced particle-light interactions in the ultra-high-Q resonators. It allows us to detect and precisely characterize the adsorbed nanoparticles in the sensing volume. The self-reference feature of the technique enables superior noise suppression in a single-shot measurement of nanoparticles. We demonstrated detection of nanoparticles with radius down to 30 nm, achieving the smallest dielectric particles detected/sized using resonators. Our method requires neither labeling of the particles nor apriori information on their presence in the medium. It provides a simple, inexpensive, fast and all-optical system for investigation and characterization of various nanoparticle systems.

7682-11, Session 4

Ultra-sensitive label-free biosensing by using single-mode coupled microcavity laser

L. Xu, Fudan Univ. (China)

Up to now, most of biosensors using microcavities are passive sensors. Active sensors (sensor itself is a laser) are not competable with passive sensors when issue of spectral resolution is concerned. Here we report a novel label-free optical bio-sensing scheme by using single mode coupled microcavity laser. We demonstrate that slight change of coupling coefficient due to the existence of bio samples leads to sensitive single mode laser hopping to a new frequency that is several nm away from the original mode wavelength. By monitoring the emergence of the hopped laser mode intensity, the lowest detectable concentration of bovine serum albumin (BSA) about 80pg/mL was obtained, which is comparable to the detection limit of a passive microcavity sensor with Q > 1E7, but with much simplified experimental setup. Combining mode hopping and mode shift, the single frequency coupled cavity laser provides a detection range from pg/mL (limit of mode hopping) to microgram/mL (limit of mode shift). Our results show the possibility of using a coupled optical microcavity to achieve ultra-sensitive optical sensing.

7682-12, Session 4

An enhanced biosensing model in coupled optical microresonators

Y. Xiao, Peking Univ. (China); L. Yang, Washington Univ. in St. Louis (United States)

Over the past few years, biological and chemical sensors based on microresonators have attracted much attention because they provide the significant advantages of high sensitivity, real-time response, minimal sample requirement, compatibility with microfluidics, and eliminating the requirement for fluorescent labeling. In the resonator-based sensors, the light photons interact with the target molecules multiple times, which builds up the changes of the signal induced by the interactions. Specifically, the mode shift or transmission change at a fixed wavelength in response to variation of the effective optical path length is utilized as the sensing signal. Resonance of a single cavity usually has a Lorenzian lineshape, which is symmetrical with respect to the resonant wavelength. Recently, a coupled-cavity configuration, consisting of a Fabry-Perot and ring cavities, has been proposed to give an asymmetric lineshape. This structure provides a larger transmission slope as compared to a single resonator, and enables improved sensitivity in sensing.

Here we theoretically propose an alternatively coupled-microcavity geometry. Coupled microcavities support very sharp asymmetrical Fano resonances, which give rise to faster changes in output transmission than the changes from a single cavity. With the output transmission at a fixed wavelength that varies much faster than it does in a single-cavity resonance, the result is enhanced sensitivity of the device to the changes in refractive index. In addition, it is observed that both thermal and optical Kerr effects can be utilized to improve the sensitivity by choosing the appropriate working points.

7682-13, Session 4

A fiber tip microresonator excited by radiation pressure for mass detection

C. Ma, A. Wang, Virginia Polytechnic Institute and State Univ. (United States)

A mechanical resonator was fabricated on the tip of a standard single mode fiber with outer diameter of 125 μm. The fabrication process involved single-mode to multimode fiber splicing, sputtering coating of submicron gold nano-film, focused ion beam (FIB) patterning and wet etching. A micro-sized vibration plate with four suspension arms with sub-micron thickness were formed on the sensing fiber tip, the resonance frequency of the vibrator is very sensitive to mass loading on its surface. Vibration was excited by modulated laser excitation and detected by another CW laser beam at another wavelength. The detected intensity of the fundamental oscillation and higher order harmonics can be monitored for resonance determination. The excitation and detection beam were multiplexed into the single sensor head, which makes the sensor extremely compact and versatile. The resonator maintained high quality factor in air and was successfully applied to the analysis of layer-by-layer polymer film self-assembly.

7682-14, Session 5

Parallel microfluidic arrays for surface plasmon resonance imaging

E. Lagally, The Univ. of British Columbia (Canada)

Protein interactions are of fundamental importance in biology and medicine. Surface Plasmon Resonance imaging (SPRi) is a label-free technique used for the quantitation of binding affinities and concentrations for a wide variety of target molecules, including proteins. Although SPRi is capable of determining binding constants for multiple ligands in parallel, current commercial instruments are limited to a single analyte stream at once. Measurement of binding kinetics requires the serial introduction of different target concentrations; such repeated experiments are conducted manually and are therefore time-intensive. To address these challenges, we have developed an integrated microfluidic array using soft lithography techniques for high-throughput SPRi-based detection and determination of binding affinities. The device consists of 264 element-addressable chambers isolated by microvalves. The resulting 700-pL chamber volumes, combined with a serial dilution network for simultaneous interrogation of up to six different target concentrations, allows for further speeding detection times through reaction-rate limited kinetics. Finally, since each chamber can be addressed independently, this array is capable of interrogating binding events from up to 264 different immobilized ligands against multiple targets in a single experiment. We envision this technology to be of use in affinity reagent selection, drug discovery, and interactome screening. We present results of protein-aptamer binding kinetics as well as preliminary biomarker detection from crude mammalian cell lysates using microfluidic SPRi, indicating the possible application of this technology to routine clinical diagnostics.

7682-15, Session 5

Lensless digital holography for telemedicine

A. Ozcan, Univ. of California, Los Angeles (United States)

Despite the rapid progress and the recent renaissance that we have been experiencing in optical microscopy and imaging, most of the advanced imaging modalities still require complex and costly set-ups that unfortunately limit their use beyond well equipped laboratories. In the meantime, microscopy and diagnostics in resource-limited settings have requirements significantly different from those encountered in advanced laboratories, and such imaging devices should be cost-effective, compact, light-weight, and appropriately accurate to be usable

by minimally trained personnel. Towards this end, here we present an on-chip cytometry platform that utilizes cost-effective and compact components to enable digital recognition and microscopic imaging of cells with sub-cellular resolution over a large field of view without the need for any lenses, bulky optical components or coherent sources such as lasers. This holographic imaging and diagnostic modality has orders of magnitude improved light collection efficiency and is very robust to misalignments which eliminates potential imaging artifacts or the need for realignment, making it highly suitable for field use. We demonstrate the performance of this platform for microscopic imaging and automated counting of whole blood cells with minimal sample preparation steps yielding spatial information at the sub-cellular level. Because this platform utilizes compact and cost-effective components that are also misalignment tolerant it may provide an important toolset for telemedicine based cytometry and diagnostics applications especially in resource poor settings for various global health problems such as malaria, HIV and tuberculosis.

7682-17, Session 5

Atto-Mollar cancer markers concentration detection using optical CMOS biosensor

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There is widespread demand for a low-cost, highly-miniaturized, rapid, selective and highly-sensitive detection method for low-abundance cancer markers detection. The detection of weakly expressed proteins and protein complexes in biological samples down to single-molecule level represents a major challenge for the scientists, due to the difficulty to achieve an acceptable level of signal-to-noise ratio. In addition, analysis of low abundance analytes can take several hours to days to give accurate results, and require bulky, expensive equipment. In this work, highly miniaturized and integrated lab-on-a-chip system has been developed comprising fluorescence CMOS reader, microfluidics, analyte manipulation/concentration system and novel amplification strategy for the binding event signal in the microfluidic system. The integrated compact and portable developed CMOS system showed unprecedented sensitivity for ultra-low disease markers concentrations.

A high sensitive phototransistor 32 x 32 arrays have been developed for biosensor detection using CMOSP35 process. High-gain emitter inversion layer VPNP emerges in CMOS technology to design phototransistor array, to enhance the electrical characteristics of CMOS analogue, as a result the current gain is improved. In such technology, diffused source/ drain junctions are commonly used as merged VPNP emitters."

7682-18, Session 6

Gas detection techniques with fiber optical spectrum absorption at near-IR wavelength

T. Liu, Tianjin Univ. (China)

Detection of pollution gas is important in environmental and pollution monitoring, which can be used widely in mining and petrochemical industry. Fiber optical spectrum absorption (FOSA) at near-IR wavelength is widely used in gas detection due to its essential advantages. It has attracted considerable attention, and there are several types and methods in FOSA. Wavelength modulation technique (WMT) is one of them, which will improve the gas detection sensitivity dramatically. This technique can be realized by detecting the intensity of the 2nd harmonic component signal. Intra-cavity laser spectroscopy (ICLS) is another alternative technique for high sensitivity absorption measurement. With an absorber directly placed within the laser cavity, a short absorption cell can be transformed into a high sensitivity system. But the practical sensitivity is obviously less than the theoretical value. The authors did some works in this field and have obtained some remarkable

progress. With broad reflectors instead of FBG as mirror of the cavity and wavelength sweep technique (WST), several absorption spectra of detected gas can be collected. And the detection sensitivity can be enhanced sharply by averaging the results of each spectrum, with acetylene sensitivity less than 100 ppm. When ICLS is used combined with WST and WMT, the detection sensitivity of acetylene can be enhanced further. The sensitivity is less than 75 ppm. By using FBGs as wavelength references, the absorption wavelength of the detected gas is obtained, which can be used to realize gas recognition. The system is capable of accessing into fiber intelligent sensing network.

7682-19, Session 6

Side-coupled optical fiber devices for sensing applications

Y. Zhang, H. Xiao, T. Wei, X. Lan, H. Duan, Missouri Univ. of Science and Technology (United States)

Recently, it was discovered that the optical power transmitted in the core of an optical fiber could be coupled into another fiber through evanescent field. The energy coupling is a sensitive function of the coupling condition as well as the surrounding environment. This coupling mechanism can thus be used to develop new optical fiber sensors for measurement of temperature, displacement and refractive index. In this paper, we experimentally investigate the light coupling effects between two parallelly aligned optical fiber devices towards various sensing applications. Two specific side-coupled devices are studied, including the side-coupled long period fiber grating (LPFG) and the side-coupled core-cladding mode interferometer (CCMI). The output spectra of these side-coupled devices are studied as a function of the order of the cladding mode, the overlapping distance, the separation distance and the refractive index of the surrounding environment. The characterization results are used to guide the design of displacement and refractive index sensors.

7682-35, Session 6

Advancements in optical measurements for harsh environment sensing in fossil energy applications

R. R. Romanosky, S. M. Maley, U.S. Dept. of Energy (United States)

The National Energy Technology Laboratory (NETL) under the Department of Energy (DOE) Fossil Energy (FE) Program is leading the effort to develop near zero emission power generation systems with the overarching goal of providing clean affordable power using domestic resources. Highly efficient, low emission power systems have extreme conditions of high temperature, high pressure, and corrosivity that require monitoring. Sensing in these harsh environments can provide key information that directly impacts process control and system reliability. Advancements in sensing using optical techniques and optical fibers are key efforts within NETL's sensor development program as these approaches offer the potential to survive and provide critical information about these processes. The lack of suitable measurement technology serves as a driver for the innovations in harsh environment sensor development. Novel approaches to fiber device design concurrent with materials development serves as motivation for advancements in this technology area. Research and development in modified and coated silica and sapphire fiber based sensors for single point and distributed measurements of temperature, pressure, strain, and a select suite of gases will be addressed. Challenge at the research level through transition of viable technology will also be outlined. The close coupling of the sensor program with process modeling and control will be introduced for the overarching goal of clean power production.

7682-20, Session 6A

Proton conducting Perovskite-type ceramics for fiber optic sensors for hydrogen monitoring in high temperature and complex environment

X. Tang, K. Remmel, D. Sandker, Z. Xu, J. Dong, Univ. of Cincinnati (United States)

The production of hydrogen and syngas (mainly H2+CO) from biomass and coal gasification and shift reactions is anticipated to play a major role in future power generation by advanced turbine and fuel cell technologies. The ability of in-situ measurement of the gas composition is needed for intelligent process control to improve the energy efficiency, system reliability, and emission reduction. However, current electrochemical hydrogen sensors are incapable of direct deployment and safe operation in the high temperature and corrosive environments involved in the hydrogen/syngas production and utilizations. New sensors are thus under strong demand to bridge the technical gaps of in-situ gas measurement in the related harsh conditions. Small size fiber optic devices integrated with chemically sensitive photonic materials are emerging as a new class of high performance optical chemical sensor that have the potential to meet many analytical challenges in future clean energy systems and environmental management. Recently, we demonstrated the integration of a proton conducting perovskite oxide thin film with a long-period fiber grating (LPFG) device for high temperature in situ measurement of bulk hydrogen in fossil- and biomass-derived syngas (Analytical Chemistry, vol. 81, pp7844-7848, 2009). In this paper, we investigate a number of proton conducting cerate- and zirconate-based perovskite oxides as high temperature hydrogen sensing materials, i.e. the nanofilm coatings, and try to understand the relationships between the perovskite materials' properties and the sensors' performance.

7682-21, Session 6A

Lithium niobate (LiNO$_3$) coated core optical fiber strain sensors

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Optical fiber sensors offer distinct advantages for infrastructure health and security monitoring. Previous research and demonstration of fiber optic sensors mostly involved Bragg grated optical fibers. Relative to electro-mechanical sensors, Bragg grated sensors and interferometers cost more, are complex and do not have a long service record. Lithium Niobate (LiNO3) coated core optical fibers consist of single mode optical fibers with 40 to 60 nm layer of LiNO3 between the glass core and cladding. LiNbO3 is a crystal with good electro-optic and piezo-optic properties. The index of refraction (n) of thin film LiNbO3 is much greater than both the glass core and cladding and changes with application of electric field or induced strain. The LiNbO3 layer acts as a preferential path for much of the light passing through a coated core optical fiber segment. Because the index of refraction changes with strain, the intensity of transmitted light becomes modulated in response to the state of loading. Relatively inexpensive light sources and photon detectors were used to examine the performance of LiNbO3 coated core optical fiber sensors. Observations of monotonic and slow cyclic tests on aluminum "dog-bone" specimens, with both LiNbO3 and conventional electro-mechanical sensors, and responses of LiNbO3 fiber to induced vibrations are presented. The results indicate LiNbO3 coated core optical fiber sensing systems are relatively simple and inexpensive but have good sensitivity and dynamic range.

7682-22, Session 7

Enhanced directional sensitivity of a biomimetic MEMS acoustic localization sensor

D. Gee, L. J. Currano, U.S. Army Research Lab. (United States); H. Liu, M. Yu, Univ. of Maryland, College Park (United States)

Miniature directional microphones are a critical component in the development of unobtrusive threat detection and target acquisition systems. We present an improved microfabricated sound localization sensor that mimics the auditory organ of the parasitoid fly, Ormia Ochracea. The device consists of two silicon diaphragms that are mechanically coupled with a suspended thin-film beam. The coupling amplifies the difference in time response between the two membranes dependent on the incident angle of the sound source. The thin-film material properties were characterized and efforts were taken to improve diaphragm separation. A parametric study has shown enhanced acoustic cues for devices with central pivoting anchors. Using laser Doppler vibrometry, amplification of time delay up to an order of magnitude were measured at 90º incident angles. The corresponding directional sensitivity of .39µs/degree improves upon previous work by 30%. These results provide a foundation for realizing an accurate bio-inspired MEMS directional microphone.

7682-23, Session 7

Performance analysis of a high-resolution wide-angle foveated optical system

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Foveated imaging addresses the need for compact wide-angle imagers capable of acquiring and transmitting high-resolution video images in real time. Optical foveated imaging using liquid crystal (LC) spatial light modulators (SLMs) has received considerable attention in the recent years as a potential approach to reducing size and complexity in wide-angle lenses for high-resolution foveated imaging. The principle behind optical foveated imaging is to cover a wide field-of-view (FOV) with a relatively simple and compact low-resolution lens, and use an LC SLM to correct wavefront aberrations at any selected field point. The SLM correction provides a high-resolution fovea that can be actively moved anywhere within the FOV. In this paper we propose a very compact design for an 18 mm F/2.8 visible monochromatic foveated optical system (FOS) covering a total diagonal FOV of 80 degrees and capable of achieving a resolution of 100 MPixels. The diffraction efficiency and the modulation transfer function (MTF) of the FOS were estimated and compared to an equivalent conventional wide-angle lens. Fabrication and assembly tolerances as well as limitations of the current transmissive LC SLM technology were taken into consideration.

7682-26, Session 7

Soldier sensor

D. Kossives, Clear Align (United States)

A new chemical sensing technology has been invented that is functionality not reliant on mass spectrometric or ionization methodology and could be miniaturized for chemical specific identification including the identification of IED precursors and biological threats.

This optical technology combines miniaturized opto-electronic packaging with a compact control circuit to create a simple device with unique, modular, chemical-specific sensors. Initial sensors to be developed will utilize existing biologic and chromic compounds. Chromic compounds enable a reversible reaction chemistry or self cleaning functionality that addresses saturation issues and enables constant re-measuring of changes in environmental threats. The sensing calculation in the device is based on simple changes in optical properties such as absorption,

reflection or color. The time to saturation and reset of the sensor is used to determine the relative chemical concentrations in the air. A detection scheme based on these properties is conceived to function in environments with high background levels and still have the ability to detect low level changes.

The completed sensor system is envisioned to be assembled with COTS optoelectronic technology and available chromic compounds and could be an ideal solution for supporting covert operations.

7682-27, Session 8

Integrated hybrid sensing platforms

E. Forzani, A. Prabhakar, R. Wang, I. Negi, A. Rui, K. Tanwar, L. Zhang, R. Iglesias, F. Tsow, N. Tao, Arizona State Univ. (United States)

We present our recent results and developed capability to integrate chemical sensing platforms at system level. Optical detectors assisted with convenient sample collectors, specific probes and complementary detection modes are integrated into sensing devices, allowing detection of analytes in real complex environments. The sensing device performance is optimized at chemical, electrical, computing and communication level. We present this integrative approach as a key element that allows us to produce chemical sensing systems capable to challenge real-world applications. Examples of portable and chemical sensing devices for monitoring of indoor-outdoor environments and breath are presented.

7682-28, Session 8

A new method for high-performance DNA sequencing

Z. Lu, Southeast Univ. (China)

BACKGROUND

In the post-genomic era, the most exciting goal is to obtain the personal genomic data for predict and prevent the potential diseases, and cure the diseases with personal therapies. Recently, large efforts have been made to identify polymorphisms (such as SNPs) and mutations in the individual DNA genomics, which will be applied in efficiently search of the functional genes, pharmacogenomics, and future individual medicine. However, the most complex disease involves many key genes and each dysfunctional gene could be mutated at many different possible positions. That is the reason that finding the disease genes needs tremendously labors and experiences, which made difficulties in the study of the functional genomics.

Until now, DNA sequencing is still critical to the identification of mutations underlying disease. Sanger DNA sequencing is one of the most important scientific technologies. However, the conventional DNA sequencing method uses electrophoresis, in which the main problems are sequencing throughput, cost and time-consuming. Recently, the exploration for low cost and high-throughput DNA sequencing is being attracted more and more attentions, and tremendously developments have been being achieved[1-5]. The most important approaches are next generation of DNA sequencers which is based on the microarray chip platforms on which genomic DNA (gDNA) fragments fixed arbitrarily on the solid substrates and formed as an random gDNA microarray, and high resolution images of fluourescence or chemical illumination were taken from the gDNA microarray during the nucleotide extension process according the gDNA templates[6-10]. More recently, the next-next generation of DNA sequencers have reported which is based on the single DNA sequencing[11-16]. However, at present, the practical low cost and rapid DNA sequencing methods are still based on the DNA sequeinxing library made of amplified monoclone DNA miroarray. The present DNA sequencing can not be meet the requirement of personal genomic DNA sequenicng, specially their cost, speed and accurary should be further improved.

Methods

We are developing a novel microarray platform for ultralow cost DNA sequencing. Here we adopted a new route to prepare the DNA templates with rolling cycle amplification (RCA) for whole genome sequencing. In our sequencing route, the sequenced DNA template array is fabricated by arbitrarily immobilizing single long DNA molecules containing multi-copies of gDNA fragments. Our experimental procedure can be described as follows. The genomic DNA is isolated from the samples, and fragmented into between 200bp and 500bp by ultrasonic power. The fragmented DNAs are linked with the common primes at each end, and hybridized to a short common single stranded DNA on which the ligation reaction occurs to form single stranded circle DNAs. The circle DNAs are hybridized and roll-amplified along a short DNA prime on the solid surface where the primers have been immobilized randomly. The single long DNA molecule array with multiple copies of the fragmented DNA is formed on the glass surface. The sequencing by synthesis has been used to sequence DNA templates with our new developed alpha-thiosequencing technology. The fluorescent signal is captured to determine the extension status of each nucleotide.

RESULTS

The sequencing route shows potential to achieve homogeneous amplification in human genome-wide during preparation of sequenced templates. The fragmented DNAs are linked with the common sequences at each end, and formed as circle DNAs. The circle DNAs are hybridized and rolling along a short DNA prime on the solid surface where the primers have been immobilized randomly, and prime DNAs are extended by DNA polymerase. The single long DNA molecule array is formed on the glass surface, and ultrahigh densely microarray of DNA molecules each with thousands of copies of one DNA fragment about 200-500 bps for human genomic sequencing templates were formed, which can cover more than 80% through cDNA microarray experiments.

The alpha-thiosequencing technology can be effectively used for faster and lower-cost DNA sequencing due to its efficient enzyme reaction. We have designed a dual check operation for each sequenced base during the new sequencing route without adding too much operation steps, which have potential to increase greatly the sequencing accuracy.

Our sequencing route has great potentials to overcome the limitations of amplification bias of whole human genome during preparation of sequenced templates by PCR, which is considered to be difficult in amplifying all fragments of the sequences from all human genome. We also developed the prototype of DNA sequencer. The read length can also be increased effectively by simply using the fluorescence quenching process. Our preliminary results showed that our whole genome sequencing strategy is promising in realizing the ultra-low-cost whole genomic sequencing.

7682-29, Session 8

Characterization of mode dependent response of LPFG for simultaneous measurement of strain and temperature

Z. Zhou, Harbin Institute of Technology (China) and Missouri Univ. of Science and Technology (United States)

Long period fiber grating (LPFG) sensor has been wildly explored for sensing various parameters such as strain and refractive index. However, temperature cross-sensitivity has been an issue. Recently, we found that LPFGs have a mode-dependent response to strain. LPFGs with cladding mode of LP06 or higher exhibit a positive shift of resonance wavelength in response to strain increase, while LPFGs with cladding modes of LP05 or lower have a negative shift in response to strain increase. On the other hand, the temperature sensitivity of LPFG remains positive for all cladding modes. In this paper, the mode-dependent temperature and strain responses of LPFGs are characterized experimentally. The characterization results are used to design single and cascaded LPFGs with cladding modes of opposite signs of strain coefficients for simultaneous measurements of temperature and strain. The principle is demonstrated using LPFGs written by point-by-point CO2 laser irradiation. The applications towards structural health monitoring (SHM) are also discussed.

7682-30, Session 8

High-power pulsed 976-nm DFB laser diodes

W. Zeller, J. Koeth, nanoplus GmbH (Germany); M. Kamp, Julius-Maximilians-Univ. Würzburg (Germany)

Distributed feedback (DFB) laser diodes nowadays provide stable single mode emission for many different applications covering a wide wavelength range. The available output power is usually limited because of catastrophical optical mirror damage (COD) caused by the small facet area. In the 980 nm wavelength range the output power of DFB lasers is limited by COD to typical values of 150 mW. For some applications such as gas detection this is sufficiently high. Other applications like distance measurement or sensing in harsh environments however require much higher output power levels.

We developed a process combining optimizations of the layer structure with a new lateral design of the ridge waveguide which is fully compatible with standard coating and passivation processes. By implementing a large optical cavity with the active layer positioned not in the middle of the waveguide layers but very close to the upper edge, the lasers' farfield angles can be drastically reduced. Furthermore, the travelling light mode can be pushed down into the large optical cavity by continuously decreasing the ridge waveguide width towards both laser facets. The light mode then spreads over a much larger area, thus reducing the surface power density which leads to significantly higher COD thresholds. DFB lasers based on this concept emitting at wavelengths around 976 nm yield hitherto unachievable COD thresholds of more than 1.5 W under pulsed operation. The high mode stability during the 50 ns pulses means such lasers are ideally suited for distance measurement or similar tasks.

7682-31, Poster Session

SDM propagation model for multiple channels using electromagnetic theory and vortex analysis

S. H. Murshid, E. Zahir, Florida Institute of Technology (United States)

Spatial Domain Multiplexing (SDM) is a novel technique in optical fiber communications. Single mode fibers are used to launch Gaussian beams of the same wavelength into a multimode step index fiber at specific angles. Based on the launch angle, the channel follows a helical path. The helical trajectory is explained with the help of vortex theory. The electromagnetic wave based vortex formation and propagation is mathematically modeled for multiple channels and the results are compared against experimental and simulated data. The modeled output intensity is analyzed to show a relationship between launch angle and the electric field intensity.

7682-32, Poster Session

SDM propagation model for multiple channels using ray theory

S. H. Murshid, E. Zahir, Florida Institute of Technology (United States)

Spatial Domain Multiplexing (SDM) is a novel optical fiber multiplexing technique where multiple channels of the same wavelength are launched at specific angles inside a standard step index multimode carrier fiber. These channels are confined to specific locations inside the fiber and they do not interfere with each other while traversing the length of the fiber. Spatial filtering techniques are employed at the output end to separate, route and process the individual channels. These skew ray channels inside the SDM system follow a helical trajectory along the fiber. The screen projection of the skew rays resembles a circular polygon. A ray theory based mathematical model of the SDM system is presented and simulated as well as experimental data is compared to the model

predictions. This ray theory model utilizes launch point, input incidence angle, and point of incidence on fiber to explain the behavior of the individual channels. Thus the vector approach to propagation allows us to predict the effects of pulse spreading in the SDM system. The results showed that the skew ray trajectory is sensitive to input incidence angle. Similarly changing the launch point, while maintaining the angle of incidence constant with the z axis, can drastically affect the skew ray trajectory.

7682-33, Poster Session

An investigation of real-time high-speed multichannel fiber Bragg grating monitoring system

T. Liu, Tianjin Univ. (China)

As one of the advance research fields in sensing technology, fiber Bragg grating(FBG) sensor has been developed rapidly in recent years. The article expatiated a new FBG strain sensor technology, which made use of DWDM into the FBG sensor system. We also proposed a new way of demodulating sensing signal, which applied the component of DWDM. Dense Wavelength Division Multiplexing(DWDM) is one of the most widely used and the most profound multiplexing technology in the optical fibre communication research and development. In recent years, the technology of DWDM has reached its maturity and widely used in business. It provided some conditions for practical promotion of FBG sensing demodulate technology. With the industrialized development of the optical fiber communication technology and maturation of grating writing technics in recent years, it is becoming possibly for practicability and industrialization of FBG sensing demodulate technology. The article was based on the technology and principle of DWDM, which was widely used in optical fiber communication systems, and made use of filter curve and technology of WDM into multichannel dynamic measurements. There are some demodulation products for fiber grating sensors, which are mostly based on passive demodulation technologies,and the samling rate is between several hertz to several hundred hertz or so, can only meet the needs of static or quasi-static measurement, but is not enough to achieve the geological monitoring in dynamic environment.In order to adapt the requirement of dynamic measurement, increasing the sampling and transmission speed of the fiber grating demodulation is needed. In this article, the wavelength demodulation range of the system is about 0.7 nm, and the precision can be 10~17 pm.

7682-34, Poster Session

Microstructured optical fiber for simultaneous measurement of refractive index and temperature

P. Lu, L. Men, K. Sooley, Q. Chen, Memorial Univ. of Newfoundland (Canada)

Optical sensors realizing in-situ monitoring of physical, chemical, and biological parameters are of great importance for process control in manufacturing industries, protection of ecosystems, and prevention of global warming. Refractive index (RI) and temperature are the most important parameters in these applications. Among different types of sensors, fiber-optic sensors possess many unique advantages over their electrical counterparts including immunity to electromagnetic interference, higher sensitivity, smaller size and weight, and the possibility of distributed measurement over a long distance. In this paper, we report an approach to achieve simultaneous measurement of refractive index and temperature by using a Mach-Zehnder interferometer realized on a tapered single-mode optical fiber. Electrical arc method has been adopted to fabricate the abrupt tapers in the fiber. The tapers, which are microstructures made on fiber, can be used to control the propagation of light between the fiber core and the cladding. The attenuation peak wavelength of the interference with specific order in the transmission spectrum shifts with changes in the environmental refractive index

and temperature. By utilizing S-band and C/L-band light sources, simultaneous discrimination of refractive index and temperature with the tapered fiber Mach-Zehnder interferometer is demonstrated with the corresponding sensitivities of -23.188 nm/RIU (refractive index unit) and 0.071 nm/oC, and -26.087 nm/RIU (blueshift) and 0.077 nm/oC (redshift) for the interference orders of 169 and 144, respectively. With the advantages of low-cost simple fabrication technique, the technique offers the possibility to adjust the taper configuration to satisfy different applications.

Conference 7683: Energy Harvesting and Storage: Materials, Devices, and Applications

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Energy Harvesting and Storage: Materials, Devices, and Applications

7683-01, Session 1

Nanostructured electrode materials for Li-ion battery

P. Balaya, National Univ. of Singapore (Singapore)

Nanostructured materials have triggered a great excitement in recent times due to both fundamental interest as well as technological impact relevant for lithium batteries. Size reduction in nanocrystals leads to a variety of unexpected exciting phenomena due to enhanced surface-to-volume ratio and reduced transport length. We will consider a few examples of nanostructured electrode materials to achieve high storage and high rate performances for lithium-ion batteries.

(a). $LiFePO_4$ nanoplates synthesized using solvothermal methods could store Li-ions comparable to theoretical capacity at C/10, while at 30C, they could exhibit storage capacity up to 45 mAh/g. Size reduction (~30 nm) at the b-axis favorable for Li-ion diffusion along with ~5 nm carbon coating enable fast insertion/extraction of both Li-ions as well as electrons.

(b). Mesporous-TiO_2 with high surface area (157m2/g) synthesized using soft-template method exhibits high volumetric density compared to commercial nanopowder (P25), with excellent storage behavior. C16 meso-TiO_2 synthesized from CTAB exhibits reversible storage capacity of 288 mAh/g at 0.2C and 128 mAh/g at 10C.

(c). Zero strain $Li_4Ti_5O_{12}$ anode material has been synthesized using several wet chemical routes; the best condition has been optimized to achieve storage capability close to theoretical limit of 175 mAh/g at C/10. At 10C, we could retain lithium storage up to 70 mAh/g.

(d). We report our recent results on alpha-Fe_2O_3 and gamma-Fe_2O_3 using conversion reaction, providing insight for a better storage capability in gamma-phase than the alpha-phase at 2C. It is seen that insignificant SEI is formed in gamma-Fe_2O_3 at high rate. At low potential, we observed extra lithium storage due to interfacial mechanism, resulting solely from the nanocrystallinity.

7683-03, Session 1

All-solid-state Li-ion batteries: seen from a multidimensional point of view

P. H. L. Notten, Technische Univ. Eindhoven (Netherlands)

Micro-batteries are expected to become more and more important in numerous small-sized devices, like medical implants, biosensors, hearing aids and autonomous network devices. Characteristic for these electronic applications is that they have to operate autonomously and reliably without any risk of electrolyte leakage. Hence they need to be rechargeable and have an extremely long cycle life. As the average energy consumption of these future devices will be rather small, this opens up the possibility to integrate all-solid-state rechargeable batteries.

It has been reported that all-solid-state, Li-based, rechargeable batteries can be charged and discharged more than 10,000 times without significant degradation. These thin-film batteries are, however, planar-structured, resulting in a relatively low energy density. By depositing the complete battery stack in a 3D etched substrate, obtained by for example physical or wet-chemical etching of mono-crystalline Silicon-wafers, the effective energy and power density can be tremendously increased. Moreover, utilizing novel battery anode materials with high storage capacity comprising of thin films electrodes are highly beneficial.

Anisotropic etching of 3D geometries (e.g. pores, trenches and pillars) in Si has been accomplished by reactive ion etching. Step conformal deposition of the various passive and active battery layers into these structures has been addressed by Chemical Vapor Deposition (CVD) and Atomic Layer Deposition (ALD). In this presentation the concept of the

3D-integrated battery will be outlined together with the presentation of experimental results. Electrochemical characterization of various battery layers will be addressed.

7683-04, Session 1

Research status of electrode materials with high capacity for Li-ion battery

Y. Yang, Xiamen Univ. (China)

In recent years, many efforts have been put into the developments of battery in power-type for (hybrid)-electric vehicles. For example, $LiFePO_4$ has been widely investigated as a new generation of cathode materials for Li-ion batteries. The safe, cheap and environmental-friendly characteristics of the materials make them an excellent candidate. However, the one of disadvantages of $LiFePO_4$ is their low capacity and lower energy density (~ 600 Wh/kg), its energy density is not satisfied to develop large-size batteries for pure electric vehicles. In order to search some new systems in high energy density, new cathode materials with high capacity and high potential should be developed. In this presentation, some new results about novel cathode materials investigated in this lab such as silicates, fluorides and novel organic electrode materials will be presented and compared. Although these new materials show some promising results in energy density, they all have some intrinsic deficiency such as structural stability and reversibility in reaction process. In addition, some new results about structural characteristics of the silicates such as $Li_2Mn_{0.5}Fe_{0.5}SiO_4$ investigated by EXAFS and In-situ XRD with synchrotron sources and Solid NMR will be presented. It seems that if we hope to explore some new Li-batteries systems with high energy density, new electrode/electrolytes materials, different reaction routes/mechanisms and new ideas should be explored in the future.

7683-05, Session 1

Tactical energy independence: creating energy abundance, efficiency and diversity

B. K. McQuiston, Defense Advanced Research Projects Agency (United States)

DARPA's comprehensive research and development is creating technologies that can lead to tactical energy independence. We can look at new technology approaches (e.g. wind, hydro, and geothermal) and new engineering approaches with the objective being the development of indigenous energy harvesting conversion and generation technologies seamlessly integrated into a brigade scale force. Our goal is to generate cost-effective alternative energy technologies for the military addressing energy generation, conversion, control, and conservation from sustainable sources. By addressing the military's own energy needs and security, we can contribute to larger solutions that are relevant to us all.

7683-06, Session 1

Flexible and thin film energy storage devices

P. M. Ajayan, Rice Univ. (United States)

Efficient energy generation and storage presents a great challenge to several future technologies. Li-ion batteries, supercapacitors and hybrid power devices have made excellent progress in recent times, with specific relevance in powering portable electronic devices. But, with the ever increasing energy and power requirements these technologies

must be further improved and the design of these needs to reevaluated. Nanomaterials have proved to be attractive candidates in the next generation energy storage devices. The design of ultrathin, flexible and environmentally safe energy storage devices will have great potential in the future. Here we will briefly discuss some recent advances from our laboratory in the fabrication of flexible and thin film energy storage devices using nanostructured materials such as carbon nanotubes, metal nanowires and graphene. New designs of nanoscale architectures that can create interesting and more efficient energy storage devices will be considered. The future and challenges in fabricating form-fitting storage platforms with high capacities will be discussed.

7683-07, Session 1

High-power long-life olivine-based rechargeable lithium batteries

Y. Chiang, Massachusetts Institute of Technology (United States)

Nanoscale olivines are currently used in rechargeable lithium batteries for a broad range of high power, long life applications ranging in size scale from cordless power tools to electric vehicles to electric grid stabilization systems. This talk will give a status update on recently fielded applications, and will discuss the design of olivine cathode materials, in particular control of phase stability in relation to intercalation kinetics, that enables such applications.

7683-08, Session 1

Improved layered mixed transition metal oxides for Li-ion batteries

M. M. Doeff, T. E. Conry, Lawrence Berkeley National Lab. (United States)

Layered mixed transition metal oxides with the general formula Li[NixCoyMnz]O2 are currently being developed for use as cathodes in Li ion batteries. In these compounds, only Ni and Co are electroactive, whereas Mn has the nominal oxidation state of +4 and is electrochemically inert. While the composition (i.e., x, y, and z) can be varied, a number of trade-offs exist. An increase in the Ni and Mn contents lowers raw materials costs, but can result in poorer rate capability and thermal tolerance at high states of charge. Co improves rate capability but is expensive compared to Ni and Mn. Cost is a particularly important consideration for vehicular applications (plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs)), so reduction of Co content is a paramount concern. Recent work in our lab has been directed towards achieving this goal by varying compositions and by partial substitution of Co with Al. Interestingly, low levels of Al substitution improve rate capability without adversely impacting energy density via structural effects that increase the Li slab spacing and improve Li ion diffusivity. High levels of Al substitution compromise specific capacity, however, so further improvements require that the Ni and Mn content be increased and Co correspondingly decreased. Low levels of Al substitution can then be used to offset any negative rate capability and thermal tolerance effects. In this paper, we will discuss the optimization of these compositions for use in Li ion batteries.

7683-15, Session 1

Three-dimensionally integrated micro-power sources and power skins utilizing nanostructured oxide membranes

S. Ramanathan, Harvard Univ. (United States)

A great need exists for novel portable power sources that may enable revolutionary on-board energy storage and conversion capabilities. In this talk, we will present recent results from our on-going investigation into micro-power sources, particularly focusing on ultra-thin oxide fuel cell membranes fabricated on silicon platforms and integrated heterogeneously onto various structures. Further, we will discuss how one may be able to exploit such devices for portable power, as well as power generating skins that may be of interest for small scale systems. Fabrication challenges, operational ranges and basic materials science issues that require further research will also be highlighted.

7683-09, Session 2

Diagnostic studies on lithium-ion cells at Argonne National Laboratory: an overview

D. Abraham, Argonne National Lab. (United States)

The lithium-ion cell has become the front-runner in rechargeable battery technologies having found applications in industries as diverse as portable electronics, medical devices, and outer space technologies. Lithium-ion batteries are also expected to replace the nickel metal hydride battery packs used in currently available hybrid electric vehicles (HEVs) because of their higher energy storage and power densities. However, the mass commercialization of these batteries for HEV applications has been hampered by high cell costs, safety concerns, limited cell life, and poor performance at temperatures below 0°C. Research to overcome these limitations is being conducted on high-power lithium ion cells at Argonne National Laboratory, as part of the Department of Energy's (DOE's) Advanced Battery Research program. Various battery chemistries, including negative electrodes with various graphite morphologies, positive electrodes containing layered- and spinel- oxides, and electrolytes containing various salts and additives are being examined. This presentation will be an overview of the various diagnostic studies being conducted at Argonne. It will present important results, link together data from the various studies, and identify possible phenomena that can explain the performance degradation observed in these cells. Understanding performance degradation mechanisms is critical to the development of new lithium-ion cell chemistries that can meet the 15-year calendar life goal established by DOE's FreedomCar initiative.

7683-10, Session 2

Understanding Li-ion battery processes at the atomic to nanoscale

J. P. Sullivan, J. Huang, M. J. Shaw, A. Subramanian, Sandia National Labs. (United States)

Reducing battery materials to nanoscale dimensions improves performance while maintaining low cost, e.g. nanoscale LiFePO4 has fast charging rates compared to bulk, and nanoscale Fe2O3 promises higher storage capacity than graphite. However, we do not fully understand the role of the surface phases on nanoparticle LiFePO4, and the initial conversion mechanism in Fe2O3 results in irreversible lost capacity. We need fundamental understanding in order to develop new high performance batteries, but measuring electrochemical processes in nanoscale materials is especially challenging. To meet this need, we have developed MEMS-based platforms compatible with operation inside a transmission electron microscope (TEM) that enable real-time observation of electrochemical processes in Li-ion battery materials. Three approaches for in-situ characterization inside the TEM will be described: the study of the solid state reaction of lithium with layered graphene anode materials, the study of structural changes in nanowire anodes and cathodes during electrochemical polarization using ionic liquid electrolytes, and the study of structural changes in battery anode and cathode thin film materials using a MEMS fluidic platform with an encapsulated high vapor pressure electrolyte. We will describe the use of these platforms for the measurement of atomic to nanoscale structural changes in technologically-relevant nanoscale battery materials. This work was supported by an LDRD project and was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. DOE, Office of Basic Energy Sciences user facility. Sandia is a multiprogram laboratory

7683-11, Session 2

In-house fabrication and testing capabilities for Li and Li-ion 18650 cells

G. Nagasubramanian, Sandia National Labs. (United States)

The two promising battery chemistries that have spurred interest in commercial, military, and space are carbon-monofluoride (CFx)n a relatively old chemistry and the Olivine (LiMPO4) based material a relatively new chemistry. While (CFx)n is a primary chemistry LiMPO4 is rechargeable. Under an internally funded program we have developed in-house cell building and manufacturing capability in a manner that allows us the flexibility to evaluate different formulations of electrolyte and cathode materials. Our in-house facility includes equipment for: 1) electrode coating, 2) electrode slitting, 3) electrode winding, 4) cell grooving, 5) electrolyte filling, 6) cell crimping and 7) thermally abusing batteries. We also have facilities for testing cells. Electrodes coated at Sandia exhibit reproducible performance indicating uniform loading. Battery grade solvents Ethylene carbonate (EC); Propylene carbonate (PC); Ethyl methyl carbonate (EMC) and Diethyl carbonate (DEC) were used as received. We typically used a mixture organic solvents containing either 1M LiBF4 or 1 M LiPF6 salt as electrolyte.

Fabrication of 18650 Cells Using SNL's In-House Facilities: In this work, we used Kureha W#9200 anode binder for the (CFx)n and Kureha W#1300 cathode binder for the LiFePO4 cathode. Electrodes were coated on to aluminum current collector (12 microns thick) with a 3 micron carbon coating on each side. We found that a thin coating of carbon is necessary to promote adhesion of the (CFx)n and LiFePO4 materials onto the Al current collector. Complete electrochemical performance characteristics at different temperatures will be reported for these materials in coin cells and 18650-cells.

7683-12, Session 2

Nanostructured lithium/air microbatteries

M. Young, J. McDonald, C. G. Wilson, Louisiana Tech Univ. (United States)

Advances in energy storage technology have the potential to enable a paradigm change across vast spectra of applied science with consequences for our environment and national security. In particular, the chemistry of lithium metal batteries yields a theoretical energy density (11.5 kWh/kg) that is competitive with fossil fuels, making them an important factor for electric vehicle development, such as passenger cars and mobile sensors. Protected lithium electrode secondary cells also have the capability to provide an inherently lightweight and safe method of energy storage for the MEMS-based power harvesting systems of tomorrow's warfighter. However, there are still obstacles to overcome before lithium-air technology becomes a viable solution as a long life cycle secondary power source. Our study focuses on improving selective gas diffusion through the moisture barrier, and establishing economically scalable fabrication methods for the cathode structure. We show the impact on specific capacity of the cathode when using large surface area catalytic nanowires produced with anodized aluminum oxide (AAO) templates. These nanostructured catalysts are crucial for enhancing reaction kinetics. The integration of this component into the composition of the cathode is also investigated for its ability to maintain effective oxygen transport in the presence of lithium peroxide reaction products. SEM micrographs show the pore characteristics of continuously and pulsed anodized AAO templates, as well as catalyst mediated shape anisotropy of the nanowires.

7683-13, Session 2

Transition metal oxide nanowires and nanorods for lithium storage in lithium ion batteries

G. Wang, Univ. of Wollongong (Australia)

One dimensional (1D) nanostructures such as nanowires, nanotubes, nanorods and nanoribbons have been extensively investigated for a wide range of applications. Here, we present the synthesis, characterization and technological applications of several 1D nanostructures including SnO2 nanowires and -Fe2O3 nanorods.

SnO2 nanowires were synthesized by thermal evaporation combined with a self-catalyzed growth procedure. Scanning electron microscopy (SEM) observation shows SnO2 nanowires having diameters of 200 - 500 nm and lengths extending several tens of micrometers. High resolution transmission electron microscopy (HRTEM) and selected area electron diffraction (SAED) analysis identified that SnO2 nanowires grew along [100] direction with an interplannar spacing of about 0.47 nm. The electrochemical performance of SnO2 nanowires was tested as anode materials in lithium-ion cells. SnO2 nanowires show a much higher lithium storage capacity, smaller initial irreversible capacity, and higher cyclability than that of SnO2 microcrystalline powders. This improved performance should be attributed to the 1D nanowires with a large surface area and high length/diameter ratio , 2. Flute-like porous -Fe2O3 nanorods and branched nanostructures such as pentapods and hexapods were prepared via dehydration and recrystallization of hydrothermally synthesised -FeOOH precursor. The -Fe2O3 nanostructures show much better sensing performance towards ethanol than that of the previously reported polycrystalline nanotubes. In addition, the -Fe2O3 nanostructure based sensor can selectively detect formaldehyde and acetic acid among other toxic, corrosive, and irritant vapours at a low working temperature with rapid response, high sensitivity, and good stability3.

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7683-14, Session 2

Higher energy and safety of Li-ion batteries

S. Komaba, Tokyo Univ. of Science (Japan)

Higher energy density is essentially required for the next generation large-scale Li-ion batteries, especially, for EV application to realize sustainable future. We have been developing the high capacity materials for positive and negative electrodes performing in an ionic liquid electrolyte, (BMP,Li)-TFSA, which is one of hardly flammable solvents, in the LiEAD project of NEDO, Japan. We found that the positive manganese based-oxide (Li2MnO3-LiNi1/3Mn1/3Co1/3O2) showed the anomalous higher capacity (>220 mAh/g) in ionic liquid of (BMP,Li)-TFSA similar to conventional organic carbonate electrolyte. The mechanism of the high capacity was investigated from crystallographic and interfacial points of view. For negative electrode, there appear to be two problems; one is undesired intercalation of organic cations of BMP instead of Li+ into graphite and the other is collapse of higher-capacity silicon electrode leading to electrical isolation within silicon electrode. Based on our investigation in the past five years, the polyacrylate used as binder is much effective to solve the problems, therefore, we accomplished the excellent high capacity performance (>1000 mAh/g) of silicon-graphite-polyacrylate electrode in (BMP,Li)-TFSA electrolyte. We will achieve the energy density higher than 600 Wh/(kg of active material) with nonflammable ionic liquid electrolyte. These results will be one of milestones to realize both high capacity and improved safety energy storage of the next generation Li-ion batteries.

7683-16, Session 3

Next-generation defense applications for the energy storage technologies

S. Sengupta, BAE Systems (United States)

Energy needs for the next generation defense applications continues to grow. These devices include, amongst others, Handheld Display , radios, heath monitoring, and night vision. The size, weight, power requirements, and usage for each of these devices are different; the cost of the power storage device is paramount. On the other hand, airborne vehicles and ground-based platforms used for Department of Defense (DoD) missions have unique electrical power demands. Power demands are currently met using batteries with poor pulsed-power efficiencies, thus adding substantial parasitic mass. Batteries alone cannot fulfill the need of defense applications and supercapacitors can play a major role if their energy density is improved. The proposed talk will focus on the requirements of the various devices carried by the soldier and its power requirements and the applicability of the state-of-the art supercapacitor technologies.

7683-17, Session 3

Recent advances in battery technologies

R. Srinivasan, The Johns Hopkins Univ. (United States)

Electrochemical Power Sources, including batteries, fuel cells and capacitors have been in existence for over two centuries. Yet, a decade after the beginning of the 21st century, electrochemical power sources operate at less than 50% of their full capability. Advanced through "basic research" and by industrial needs since their inventions, their development occurred in three broad periods of necessities: early use in lighting and telecommunications, later in automobiles, electronics and space applications, and most recently with intense focus on volume- and weight-conscious devices such as cell phones and UAVs. Over the next decade we will see the dominance of life and performance extension technologies through power scavenging and storage, and power and energy management. Advances in nanotechnology and physic-chemical analytical tools are paving the way for these most versatile and reliable power sources to reach their ultimate potential. Recent developments in this ubiquitous yet enigmatic technology will be discussed from the users' perspective.

7683-18, Session 3

Inexpensive, scalable non-vacuum techniques for fabricating solid state lithium ion battery cathodes and batteries

E. Dayalan, R. Pitts, Planar Energy Devices, Inc. (United States);
I. Oladeji, SISOM Thin Films, LLC (United States)

Total safety in lithium/lithium ion batteries can only be achieved by going to an all solid state system. Until now functional all solid state batteries have been fabricated only as thin film micro-batteries using very expensive vacuum deposition techniques. We have developed inexpensive novel technologies for fabricating solid state battery cathodes and batteries. These techniques do not involve use of vacuum or non aqueous solvents and are inexpensive, scalable and high rate. Both thin film micro-batteries as well as large format high energy batteries can be manufactured using these techniques. Performance of the cathodes fabricated by this method will be presented.

7683-19, Session 3

Silicates and titanates as high-energy cathode materials for Li-ion batteries

R. Dominko, National Institute of Chemistry Slovenia (Slovenia)

Li_2TmSiO_4 (silicates) and Li_2TmTiO_4 (titanates) (Tm= Fe, Mn, Ni, V,...) materials represent novel high energy cathodes for lithium ion batteries with at least theoretical possibility to enable more than 1 electron reaction. They belong to the new group of active cathode materials with a theoretical capacity exceeding 300mAh/g and they offer a large possibility to improve overall energy density of current Li-ion batteries technology. Detailed structural and electrochemical characterization of some members of silicates and titanates will be discussed in the details. We are going to present a combination of different characterization techniques (in-situ and post mortem) with the aim to explain electrochemical and structural characteristics of proposed novel groups of cathode materials. During the presentation we will focus on the structure determination and on the influence of the structure and composition on the electrochemical properties and we will present some possibilities of proposed groups of materials. More precisely we will show challenges, drawbacks and potentials for both group of proposed materials.

7683-20, Session 3

Self-regulating fiber fuel cell

S. J. Eickhoff, Honeywell International Inc. (United States)

Advances in lithium primary battery technology, which serves as the gold standard power source for the dismounted soldier, have not kept pace with the ever increasing power and energy requirements of modern military electronic equipment. In applications ranging from urban and tactical unmanned ground sensors to weapons systems, GPS, and night vision, current battery technology falls short in a number of areas including power, energy, weight, and form factor. Fuel cells have long been touted as the solution to the dismounted soldier's power and energy problems, but until recently, have largely failed to live up to that promise. Indeed, as a part of the DOD's Wearable Power Prize Program in 2008, several teams demonstrated fuel cells at the 20W level that for the first time exceeded the energy density and specific energy of lithium primary batteries. There remains, however, a substantial gap between the performance of 20W-level fuel cells and their smaller counterparts generating power at watt or sub-watt levels, which the vast majority of soldier power applications require. Clearly, there is still a need for better power sources at the watt or sub-watt levels, especially in applications requiring non-traditional form factors (thin, prismatic) or those having special requirements like flexibility or conformability, where existing battery technology falls short. To address these needs, Honeywell has contracted with DARPA to develop and demonstrate a Self-Regulating Fiber Fuel Cell that utilizes a novel fuel chemistry and regulation mechanism. Moreover, we incorporate micro fabrication techniques to create a flexible, conformal power source with substantially better energy density and specific energy than state-of-the-art lithium primary batteries. This talk will cover Honeywell's progress on the Fiber Fuel Cell Program.

7683-21, Session 4

Future opportunities in power and energy devices

N. K. Dhar, Microelectronics Technology Office/DARPA (United States)

The power and energy need for modern, highly agile and network-centric systems of future capability is ever growing. The demand for higher specific energy and power is not only driven by high energy requirements, but also to meet the challenges of miniaturized systems. Therefore, one of the primary road-block towards the progress of highly specialized Microsystems technology, such as micro-UAVs and micro-robots is the

ability to meet the energy payloads. The objective warrior requirement is yet another driver towards developing new energy storage and harvesting technology. Therefore, it is a clear observation that the current power and energy devices is not keeping up with the scaling in the sophistication and miniaturization of various systems platforms. Conventional prismatic designs and form-factors may not meet the challenges of the future in military systems. It is certain that the energy devices of the future would have to be conformal, multi-dimensional and integrated. This talk will highlight few opportunities toward future power and energy possibilities.

7683-22, Session 4

Overview of the present status and research opportunities for CdTe thin film solar cells

R. G. Dhere, D. S. Albin, X. Li, T. A. Gessert, National Renewable Energy Lab. (United States)

Recent success of thin-film solar cells with First Solar's meteoric rise has attracted considerable public attention. First Solar, already the largest producer of photovoltaic cells and modules in the United States, will be contending for the top spot worldwide. We will present an overview of different industries involved in the field and their approaches. The rapid growth in the industrial activity is creating a false sense of technology maturity in different quarters. We will highlight key developments during the last forty years that have been stepping stones for progress in device performance. In addition, we will present the research going on at our laboratory (NREL) and others, and we will discuss the status of the research and significant challenges. The champion CdTe cell has an efficiency of 16.5%, and module efficiency based on present knowledge is expected to reach about 12.5%, which is well below its potential. We will present our analysis of the device performance and the main parameters affecting the performance. Further improvement in module performance is unlikely without better understanding these parameters. Other areas of emphasis are long-term reliability and accelerated life testing that is necessary to understand the effect of processing changes on product reliability. This abstract is subject to government rights.

7683-23, Session 4

Multijunction single-crystal CdTe-based solar cells: opportunities and challenges

S. Sivananthan, EPIR Technologies, Inc. (United States)

Three-junction solar cells utilizing single-crystal III-V semiconductor homojunctions grown on Ge substrates have demonstrated very high efficiencies, up to 41.1% in the lab and 39% in manufactured form under optimal solar concentrations and 32% under one-sun illumination, but are inherently very expensive. Multijunction II-VI cells manufactured by high-throughput molecular beam epitaxy on silicon substrates would cost almost an order of magnitude less. We present calculations of III-V and II-VI multijunction cells and preliminary experimental results for single-junction and tandem (two-junction) cells using CdTe-based alloys grown on silicon. These results suggest that multijunction II-VI based cells also will yield substantially higher efficiencies than the corresponding multijunction III-V based cells. They suggest that even an optimized II-VI/Si tandem cell will reach 32%, the highest one-sun efficiency recorded for any III-V multijunction cell.

Efficiency calculations for II-VI and III-V multijunction cells are reported and compared with reported best III-V lab cell efficiencies. These results are used to predict optimized II-VI cell efficiencies. The reasons for the higher predicted II-VI cell efficiencies are explained. Measured values of open-circuit voltage (Voc), closed-circuit current (Jsc), fill factor and efficiency for single-junction and tandem II-VI/Si cells are reported. The II-VI Voc values approach the theoretical limit. Taking into account the increase in Jsc that would be produced by an antireflection coating and the increase in fill factor that would be produced by an improved contact resistance, our experimental results suggest that an optimized II-VI tandem cell efficiency of 30-34% is attainable, consistent with our theoretical predictions.

7683-24, Session 4

High-efficiency solar cells based on micro-nano scale structures

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Higher efficiency solar cells are required to reduce solar array mass, stowed volume, and cost for numerous commercial and military applications. Conventional solar cell made of thin-film or crystal-Si (c-Si) or other thin films have limited conversion efficiency of 10 to 20% with the cost of $3-$5/Wp. Current state-of-the-art crystalline multijunction solar cells are ~30 % efficient with the cost of $30 to $40 /Wp. Increasing conversion efficiency of > 30% will enable to reduce the cost < $1/Wp and useful for various power platforms supporting mobile wireless, laptop, tent applications. Solar cell comprises with three dimensional blocks are shown to be higher conversion-efficiency than standard flat-type solar cell. Incorporating nano-scaled blocks in solar cell structures are shown to be increased performances due to (i) increase of the surface area to volume ratio, (ii) bringing the junction closer to the carrier generation region which eliminates the carrier recombination , (iii) maximizing absorption of incident photon flux, and (iv) broadening the absorption spectrum. Our activities on next generation high performance solar cells based on micro-nano scaled structures and various material systems will be presented. Detailed fabrication process of micro-nano scaled solar cell friendly to mass scale manufacturing will also be described. We have achieved more than 20x optical performance enhancement for the solar cell based on micro-scaled structures, than that of flat-type (standard) solar cell, fabricated on the same Si substrate and same process. Simulation results showed that significant improvement in conversion efficiency more than 30% is possible for even c-Si solar cell based on the micro-nano scaled structures. Key issues and challenges for bringing it to the manufacturing will be discussed in the conference.

7683-25, Session 4

Application of nanotechnology to photovoltaics for energy harvesting

L. Tsakalakos, GE Global Research (United States)

In this talk a general overview of the key nanotechnology physics and materials concepts that are applicable to PV will be described. Examples of how such concepts may be applied to energy harvesting will be provided, including our work on nanowire-based solar cells [1]. The key benefits of such devices are discussed, followed by optical reflectance, current-voltage, and external quantum efficiency data for a cell design employing a thin amorphous silicon layer deposited on the nanowire array to form the p-n junction. The fabrication process will be described in detail. We have obtained a promising current density of ~1.6 mA/cm2 for 1.8 cm2 cells under simulated AM1.5G illumination. We have also shown that the optical reflectance of the silicon nanowire solar cells is reduced by 1-2 orders of magnitude compared to planar cells. Key scientific and engineering challenges in improving the performance of these nanostructure silicon-based solar cells will be described.

[1] L. Tsakalakos, et al., Appl. Phys. Lett. 91, 233117 (2007).

7683-26, Session 4

GaAs-based quantum well solar cells for defense applications

A. K. Sood, R. E. Welser, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); O. A. Laboutin, Kopin Corp.

(United States)

Quantum well based solar cells have the potential to deliver ultra-high efficiencies in single junction devices, efficiencies that in theory can approach 45% in un-concentrated sunlight over a wide range of environmental conditions. However, dramatic reductions in the dark current of GaAs-based diodes have recently been reported by using a novel device structure incorporating wide band gap material within the junction depletion region. After optimizing the field strength and barrier profile to enhance field-assisted thermionic emission, we have now also added single InGaAs quantum wells of varying thickness and composition. Record high open circuit voltages have been achieved in these materials on test structures. We will present experimental results on demonstrating high open circuit voltage for the solar cells. Our results are consistent with a suppressed radiative recombination rate and provide direct experimental evidence that the quantum well based structures can provide high efficiency solar cells for a variety of defense applications.

7683-27, Session 4

High-efficiency InN-based quantum dot solar cells for defense applications

A. K. Sood, R. E. Welser, Y. R. Puri, Magnolia Optical Technologies, Inc. (United States); O. A. Laboutin, Kopin Corp. (United States)

Nitride semiconductors possess a number of unique material properties applicable to solar cells, including a large range of energy gaps, superior radiation resistance, and tolerance to high temperatures. The wide band gap properties of GaN are well known and have enabled the creation of new solid-state lighting and high power electronic technologies. On the other hand, InN is a less well developed material with a significantly lower energy gap, possibly as low as 0.7 eV. Thus, an unprecedented range of absorption energies, ranging from the infrared to the ultraviolet, can be obtained by embedding InN-based quantum dots in a wide band gap GaN barrier. The combination of energy-gaps accessible to III-V nitride materials may also potentially be used to reap the benefits of even more advance device concepts involving hot carrier effects or multiple carrier generation processes.

We will present our results on self-assembled InN quantum dots formed on GaN templates. We have been quite successful at synthesizing InN quantum dots using MOCVD process. We will also present electrical and optical properties for high density of InN dots exhibiting excellent structural and optical properties. In this presentation, we will review our latest results, including our efforts to build InN quantum dot photovoltaic device for high efficiency solar cells.

7683-28, Session 5

Multidimensional nanoscopic approaches to new thermoelectric materials

D. S. Dudis, J. B. Ferguson, M. Check, J. E. Schmidt, Air Force Research Lab. (United States); J. A. Shumaker, C. Chen, Univ. of Dayton Research Institute (United States); H. A. Seibel, Universal Technology Corp. (United States); E. R. Kemp, Air Force Research Lab. (United States)

Significant gains in the performance of thermoelectric materials require optimization of three interconnected transport properties: electrical conductivity, thermal conductivity, and the Seebeck coefficient. We are exploring molecularly assembled materials that build on one, two and three-dimensional nanoscopic structures which allow for the separation electrical conductivity from thermal conductivity. One dimensional materials based on thermally stable phthalocyanines are being explored, while layered (two-dimensional) and bulk (three dimensional) cluster-based compounds are being prepared and characterized. Thermal conductivities as low as 0.17 W/m K have been measured in bulk pellets. Strategies and progress for all three approaches will be discussed.

7683-29, Session 5

Thermoelectric property of CdS thin film

A. H. Jayatissa, Y. X. Gan, C. Kwapich, X. Zeng, The Univ. of Toledo (United States)

Cadmium sulfide has the optical band gap of 2.42 eV or 514.5 nm (in wavelength units), which is sensitive to visible light. Thin films of CdS have found applications as detectors of light and window materials for solar cells. There is little work on the thermoelectricity of CdS. Recently, we have demonstrated that CdS thin films are very sensitive to heat. The change of surface temperature of this material results in significant increase in electrical conductivity. In this study, we focus on the heat sensitivity of CdS thin films. CdS thin film in the thickness of about 5~10 nm was prepared by thermal evaporation method. A three-electrode system was used for linear sweep voltammetry measurement. The three electrodes are connected with a electrochemical quartz microbalance to conduct data acquisition. The three electrodes are the reference electrode, the work electrode (cathode), and the counter electrode (anode). The width of the specimens is 25 mm, and the distance between the counter electrode and the work electrode is also 25 mm. It was found that the electrical conductivity of the material increased by 2 times when temperature was increased from 25 to 40 gegree C. Such a heat sensitive behavior reveals the thermoelectricity within the CdS thin film. More details in the relationship of temperature and resistance will be presented based on our on-going studies. Fundamental studies on how the temperature field causes the electron ejection are under way.

7683-30, Session 5

Solvothermal synthesis and thermoelectric properties of nanostructured skutterudites and pnictides

W. Li, L. Kumari, Florida International Univ. (United States)

Binary skutterudite (CoSb3) and pnictide (NiSb and FeSb2) nanoparticles were synthesized by solvothermal method with and without various surfactants including SDS, CTAB, Triton and PVP. The effect of the surfactants and synthesis parameters on the formation and morphology of the nanoparticles was investigated. Uniform crystalline nanoparticles with size as small as 10 nm were obtained. The crystal structure of the nanoparticles was examined and analyzed by X-ray diffraction and transmission electron microscopy. A detailed study on the UV-vis absorption, optical band gap, and photoluminescence has been performed to understand how the nanostructures affect their optic and electronic properties. Samples for thermoelectric property characterization were prepared by sparking plasma sintering technique. The thermoelectric property of sintered nanostructured skutterudite and pnictide materials was measured to reveal the correlation between the nanostructures and their thermoelectric property. The nanosized skutterudite and pnictide materials present improved thermoelectric properties and may be suitable candidates for developing thermoelectric devices for energy application with enhanced efficiency.

7683-31, Session 6

Novel metal/semiconductor nanocomposite and superlattice materials and devices for thermoelectrics

J. M. Zide, Univ. of Delaware (United States); A. Majumdar, Univ. of California, Berkeley (United States); A. C. Gossard, J. E. Bowers, Univ. of California, Santa Barbara (United States); T. D. Sands, Purdue Univ. (United States); R. J. Ram, Massachusetts Institute of Technology (United States); Z. Bian, N. P. Kobayashi, Univ. of California, Santa Cruz (United States); I. Miotkowski, Purdue Univ. (United States); L. Bell, BSST LLC (United States);

A. Shakouri, Univ. of California, Santa Cruz (United States)

Efficiency of thermoelectric materials is generally discussed in terms of the dimensionless figure-of-merit, $ZT = S^2 T/$, where S is the Seebeck coefficient,   is electrical conductivity, T is absolute temperature, and   is thermal conductivity. Many researchers have found that it is possible to reduce the lattice thermal conductivity by incorporating nanostructures (i.e. nanoparticles or heterobarriers) into materials, thereby scattering phonons. At the same time, it has been theoretically predicted and experimentally demonstrated that barriers can be used to "filter" the distribution of carriers which contribute to conduction. By doing so, it is possible to significantly increase the Seebeck coefficient while only modestly decreasing the electrical conductivity. As a result of this energy-dependent scattering of carriers, the thermoelectric power factor is increased.

We present theoretical and experimental results for metal/semiconductor nanocomposites consisting of metallic rare-earth-group V nanoparticles within III-V semiconductors (e.g. ErAs:InGaAlAs) demonstrating both an increase in thermoelectric power factor and a decrease in thermal conductivity, resulting in a large figure of merit. We also discuss metal/semiconductor superlattices made of lattice-matched nitride materials for electron filtering and the prospects of these materials for efficient thermoelectrics, especially at high temperatures. Finally, we will discuss both various synthesis techniques for these materials, including the prospects for bulk growth, and also devices fabricated from these materials.

7683-32, Session 6

Thin film superlattice thermoelectric materials and device technologies for energy harvesting applications

D. Stokes, P. Barletta, M. J. Mantini, B. Grant, R. Venkatasubramanian, RTI International (United States)

There is an increasing need for self-sufficient power sources for wireless sensors and electronics that can extend device operational lifetime beyond what is available from conventional batteries and potentially reduce size and weight. Thermoelectric power harvesting, compared to photovoltaic and vibration-energy harvesting, offers 365/24 operation and a ready transition to covert use.

Two approaches for developing thermoelectric power sources include geothermal and body heat energy harvesting. The availability of ground thermal gradients both during the day and night under a variety of environments makes this potential power source of great interest. RTI has developed a prototype "thermal ground stake" wireless sensor node powered by thermoelectric (TE) energy harvesting. The design lends itself to unattended ground sensors for covert military and intelligence operations where a TE-powered sensor is concealed in the ground. Another application involves body heat energy harvesting, where direct conversion of body heat (15mW/cm2 on average) to electricity has the potential to self-power wireless physiological sensors. RTI and Quasar, Inc. are working together to develop an integrated body-worn biosensor system powered by body heat thermoelectric energy harvesting.

In order to make use of these low-level heat sources, devices that can operate efficiently under lower delta-T's are necessary. RTI has developed nanostructured, thin-film superlattice TE devices that achieve greater than 3x the power density (per unit surface area) as compared to state-of-the-art bulk TE devices for moderate to low delta-T environments. We have built and tested such TE modules for power generation with temperature differences as low as 1K.

7683-33, Session 6

Ultra-low-power conversion and management techniques for thermoelectric energy harvesting applications

J. W. Fleming, Luna Innovations Inc. (United States)

Thermoelectric energy harvesting is increasingly gaining acceptance as a secondary power source that can be used in numerous commercial and military applications. The cyclical nature of favorable ambient conditions for energy harvesting has rendered many energy scavenging technologies unreliable as the primary power source for micro power electronics. Power electronic designers have struggled to incorporate energy harvesting methods into their designs due to the relatively small voltage levels available from many harvesting device technologies. In order to bridge this gap, an ultra-low input voltage power conversion method is needed to convert small amounts of scavenged energy into a usable form.

Focusing specifically on the ultra-low voltage power conversion technical challenges, this paper discusses the novel ultra-low voltage DC to DC converter techniques and applied technologies. Intelligent power management techniques control the unknown startup conditions. The load and supply management functionality is also controlled in a deterministic manner. The DC to DC converter output voltage is stored into a storage device such as an ultra-capacitor or lithium-ion battery for use during brown-out or unfavorable harvesting conditions. Applications requiring modular, low power, extended maintenance cycles, such as wireless instrumentation would significantly benefit from the novel power conversion and harvesting techniques outlined in this paper.

7683-35, Session 6

Harvesting vibration energy using nonlinear oscillations of an electromagnetic inductor

C. Lee, D. Stamp, N. Kapania, Franklin W. Olin College of Engineering (United States)

A series of demonstration devices have been built to study how the nonlinear response of the mechanical transducer of a vibration energy harvester can be exploited to generate more electricity than current state-of-the-art vibration harvesters. The first device is single-degree-of-freedom system that consists of tube which holds three neodymium magnets that have their poles aligned in such a way that the middle magnet 'floats' between the fixed, top/bottom magnets. The net magnetic field creates a spring force, whose force-displacement relationship can be described by a fifth order polynomial, on the middle magnet. Electricity is generated by induction in a coil around the tube. Single-frequency harmonic and random excitation is applied to the base of the device. The middle magnet exhibits a duffing-equation-like response under harmonic excitation. There is an extended frequency range in which significant power can be generated as compared to harvesters which exhibit linear response. This follows predictions from a theoretical model. Under random excitation, the harvester generates limited power due to the presence of simultaneous stable, periodic response motions. A theoretical/numerical model of a proposed multi-degree-of-freedom system whose response can be tuned so that there is only one stable, large amplitude response over an extended frequency range is presented along with preliminary experimental measurements.

7683-36, Session 6

Microcombustor thermoelectric power generator for 10-50 watt applications

D. S. Marshall, CUBE Technology, Inc. (United States)

Fuel-based portable power systems, including combustion and fuel cell systems, take advantage of the 80x higher energy density of fuel

States); P. K. Das, Univ. of California, San Diego (United States);
J. D. Pinezich, Advanced Acoustic Concepts (United States)

In many commercial, industrial, and military applications, supplying power to electronics through a thick metallic barrier, without compromising its structural integrity, would provide tremendous advantages over many existing barrier-penetrating techniques. The Faraday shielding presented by thick metallic barriers prevents the use of conventional electromagnetic power-transmission techniques. We describe the electrical optimization of continuous-wave power delivery through thick steel barriers, using ultrasonic channels formed by attaching pairs of axially-aligned piezoelectric transducers to opposite sides of thick steel blocks. The thickness of the steel considered is on the order of, or greater than, the wavelength of the acoustic power signal inside of steel, requiring the use of wave propagation theory to properly analyze the system. A characterization and optimization methodology is presented which first measures the linear two-port electrical scattering parameters of the transducer-steel-transducer channel. Using these measurements, the simultaneous conjugate impedance-matching conditions at both transducers is calculated, and electrical matching-networks are designed to optimize the power transfer from a 50 Ω power amplifier on one side of the steel block to a 50 Ω load on the opposite side. In addition, the impacts of, and interactions between, transducer and steel geometries are discussed, and some general guidelines for selecting their relationships are presented. Measurements of optimized systems using transducers designed to resonate at 1 MHz with diameters from 12.7 - 66.7 mm, and steel block thicknesses from 9.5 - 63.5 mm, reveal power transfer efficiencies as high as 55 %, and linear delivery of upwards of 81 Watts through these barriers.

7683-42, Poster Session

A high-temperature acoustic-electric system for power delivery and data communication through thick metallic barriers

T. J. Lawry, K. R. Wilt, S. Roa-Prada, J. D. Ashdown, G. J. Saulnier, H. A. Scarton, Rensselaer Polytechnic Institute (United States); P. K. Das, Univ. of California, San Diego (United States); A. J. Gavens, KAPL, Inc. (United States)

In many sensing applications that monitor extreme environmental conditions within sealed metallic vessels, penetrating vessel walls in order to feed through power and data cables is impractical, as this may compromise a vessel's structural integrity and its environmental isolation. Frequent servicing of sensing equipment within these environments is costly, so the use of batteries is strongly undesired and power harvesting techniques are preferred. Traditional electromagnetic power delivery and communication techniques, however, are highly ineffective in these applications, due to Faraday shielding effects from the metallic vessel walls. A viable, non-destructive alternative is to use piezoelectric materials to transmit power through thick metallic barriers acoustically. We present critical elements of a high-temperature battery-less sensor system prototype, including power harvesting, voltage regulation, and data communication circuitry able to operate up to 260ºC. Power transmission is achieved by aligning a pair of high-temperature piezoelectric transducers axially, on opposite sides of a thick steel barrier. Continuous-wave excitation of the outside transducer creates an acoustic beam that is captured by the opposite transducer, forming an acoustic-electric link for power harvesting circuitry. Simultaneously, sensor data can be transmitted out of the high-temperature environment by switching the electrical impedance placed across the leads of the inside transducer, creating a reflection-based amplitude modulation on the outside transducer. Transducer housing, loading, and alternatives for acoustic couplants are discussed. Measurement results are presented, and it was found that the system can harvest up to 1 watt of power and communicate sensor data up to 50 kbps, while operating at 260ºC.

7683-43, Poster Session

A two-way ultrasonic through-wall communication system with power harvesting

J. D. Ashdown, K. R. Wilt, T. J. Lawry, G. J. Saulnier, S. Roa-Prada, H. A. Scarton, Rensselaer Polytechnic Institute (United States); P. K. Das, Univ. of California, San Diego (United States); A. J. Gavens, KAPL, Inc. (United States)

A method for full-duplex two-way communication of instructional commands and sensor data through a thick steel wall channel without penetration is presented. Such a capability is of interest in sealed sensing applications to control the mode of operation of enclosed sensors without having to power down the system to reprogram. Two axially aligned piezoelectric transducers are mounted on opposing sides of a steel wall channel and a continuous wave (CW) carrier signal is applied to a transducer on the outside wall. A transducer on the inside wall modifies its acoustic impedance which, upon carrier reflection from the inside, results in an amplitude modulated (AM) signal on the carrier. Using AM modulation and envelope detection techniques, a protocol is developed which allows for the transmission of user specified commands from the outside to the inside of the channel to set the desired mode of system operation, including the data rate, while allowing for the simultaneous transmission of sensor data from the inside to the outside of the same channel. A custom 31.75 by 31.75 mm, six-layer printed circuit board is described which contains power harvesting and envelope detection circuitry and includes several on board sensors to monitor temperature, humidity, and conductivity. It is shown that adequate power may be harvested to allow for the continuous operation of several inside sensors. Also, reliable communication of sensor data is shown at rates up to 20 kbps using 25.4 mm diameter 1 MHz transducers on steel wall thicknesses ranging from 57.15 - 304.8 mm.

7683-44, Poster Session

Performance of solar cells based on their orientation

N. G. Dhere, S. A. Pethe, Univ. of Central Florida (United States)

One of the major advantages of photovoltaics is their use in remote locations where availability of energy is a luxury. Photovoltaic technology has reached maturity in terms of reliability and performance with several companies involved in commercial production of solar modules. With increasing efficiencies, potential of photovoltaics as energy source in remote locations for niche applications is being realized by researchers as well as industry. However, in various applications the liberty of deploying the solar cells in a most favorable direction or orientation that would produce maximum output power may not be always available. Hence, it becomes essential to understand the effect of deployed orientation of PV device on output and performance of the solar cell so as to develop and design the energy source for various devices accordingly. Therefore, it is essential to measure photovoltaic parameter on small area solar cells oriented in various directions to understand the effect of orientation on PV performance prior to incorporation of PV in various devices such as sensors. Therefore, efforts were undertaken at Florida Solar Energy Center to measure the device output parameters such as the open circuit voltage, short circuit current, optimum voltage and current and maximum power transferred when the solar cells were directed in various orientations. The measurements were carried out at different times of the day so that the device performance at various irradiance values. The measurements were then used to calculate the total energy produced by the solar cells over a period of one day.

7683-45, Poster Session

Quantum dot sensitized solar cells based on nanostructured zinc oxide

P. K. D. D. Pitigala, K. Tennakone, U. A. Perera, Georgia State Univ. (United States)

Solar energy conversion concepts based on nanostructured materials has attracted much attention as an avenue to develop cheaper and more efficient solar cells. Both dye molecules and quantum dots sensitize high band semiconductors and inject carriers to the conduction band of the high band semiconductor elecrtod. However, other physical properties of dye anchored, and quantum dot (QD) embedded nanostructure semiconductor films offers the possibility of designing hybrid systems of a higher efficiency. The low efficiency of dye-sensitized solar cells is partly attributed to the poor electron transport properties of the dye coated nanocrystalline matrix. Encapsulation of PbS quantum dots enhanced the electronic conductivity of nanostructured ZnO films. PbS quantum dot sensitized ZnO films shows sensitizing response to light absorption in ZnO, PbS- QDs and dyes anchored to ZnO. As a result, the improvement of transport properties by the QDs, and photocurrent response of composite system due to light absorption by ZnO and dye are also enhanced. Possibilities of adopting this concept in solar cells and multi-band photon detectors will be discussed.

7683-47, Poster Session

Structural and morphological analysis of PbTe nanostructures synthesized by solvothermal and hydrothermal route

K. Kadel, L. Kumari, W. Li, Florida International Univ. (United States)

Lead Telluride (PbTe) nanostructures were synthesized via solvothermal/hydrothermal route. The crystallinity of the as-prepared sample was analyzed by x-ray diffraction (XRD) pattern which confirms the product material is of a face centered cubic PbTe. Structure and shape of PbTe nanostructures was analyzed by TEM images which shows that PbTe nanostructures are cube shaped. The effect of addition of surfactants on shape and sizes of the nanocubes were investigated and has been discussed by surface morphology analysis. PbTe nanocubes synthesized with surfactants shows the more uniformity and well defined shape as compared to the PbTe nanocubes without surfactants. Effect of synthesis temperatures on the structure and morphology has also been discussed and found that particle size increases with temperature.

7683-48, Poster Session

Synthesis and characterization of Ruthenium dioxide nanorods

S. Neupane, L. Kumari, G. Kaganas, W. Li, Florida International Univ. (United States)

Synthesis and characterization of Ruthenium dioxide nanorods

We report the synthesis of ruthenium dioxide (RuO_2) nanorods by chemical vapor deposition technique. RuO_2 nanorods were formed at various synthesis conditions like working pressure, and oxygen and argon flow ratio. Low pressure of 1 Torr was favorable in obtaining well structured club-like nanorods at oxygen flow of 300 sccm while high quality hollow nanorods were synthesized at oxygen flow of 1800 sccm. High density pine-tree-like nanorods were grown at normal atmospheric pressure in oxygen flow of 600 sccm. Structural analysis by X-ray diffraction technique confirms the formation of rutile crystal structure with orthorhombic phase.

7683-49, Poster Session

High-efficiency integrated piezoelectric energy harvesting systems

P. L. Shah, A. Hande, Texas MicroPower, Inc. (United States)

This paper describes hierarchically architectured efficient design and development of an energy harvesting (EH) system that consists of micro and/or macro-scale harvesters matched to multiple components of remote wireless sensor and communication nodes with efficient power management. The micro-scale harvesters consist of thin-film MEMS piezoelectric cantilever arrays and power generation modules in IC-like form to allow efficient EH from vibrations. The design uses new high conversion efficiency thin-film processes combined with novel cantilever structures tuned to multiple resonant frequencies as broadband arrays. The macro-scale harvesters can be used to power the collector nodes that have higher power specifications. These bulk harvesters will be integrated with efficient adaptive power management circuits that match transducer impedance and maximize power harvested from multiple scavenging sources with very low intrinsic power consumption. Texas MicroPower Inc. (TMP) will leverage its existing exclusive license to a composition that has the highest reported energy density as compared to other commercially available bulk PZT-based sensor/actuator ceramic materials and extend to thin-film materials and miniature conversion transducer structures. We anticipate the micro-transducer power density to be at least 1.5 mW/cm2/g and the macro-transducer power density to be at least 2 mW/cm3/g. The proposed multiform factor, energy aware harvesters with their flexibility can be deployed for several military and commercial applications such as underground unattended sensors, sensors in oil rigs, structural health monitoring of bridges, roadways and aircrafts, supply chain management, and battlefield applications such as sensors on soldier apparel, equipment, intelligent ammunition, and wearable electronics.

Conference 7684:
Laser Radar Technology and Applications XV

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Laser Radar Technology and Applications XV

3D imaging laser radar using Geiger-mode APDs: analysis and experiments

Y. Guo, G. Huang, R. Shu, Shanghai Institute of Technical Physics (China)

For a direct-detection 3D imaging ladar, the use of Geiger-mode avalanche photodiode (APD) can greatly enhance the detection efficiency of the receiver since each range measurement requires only one detected photon. Single photon sensitivity of the detector offers significant advantages in reducing receiver size, mass and power and reducing laser complexity. This paper studies the 3D imaging ladar using APDs which are actively quenched and gated to operate at Geiger-mode to detect short weak laser echo pulse. The detection model of this detector as well as the detection probability and false alarm probability for this ladar is analyzed and discussed. The analysis shows that the major factors influencing system design are the background light noise and the dead time of the Geiger-mode APD. Then the noise which affects the false alarm probability is analyzed and calculated and the measures to extract the weak signal echo from a high noise background are put forward. The research also shows that using a detector array instead of a single detector could reduce the false alarm probability by orders of magnitude. Finally a 3D imaging brassboard system which utilizes Geiger-mode APDs, a fast pulse, high repetition rate laser, and an optical scanner is described, and some experimental results obtained by this system are presented and analyzed. The results suggest that if the background light noise is sufficiently suppressed, 3D images of the targets will be successfully taken by the ladar using Geiger-mode APDs.

Active 3D camera design for target capture on Mars orbit

P. Cottin, F. Babin, INO (Canada); A. M. Deslauriers, B. Sylvestre, Neptec Design Group Ltd. (Canada); D. Cantin, INO (Canada)

During the ESA Mars Sample Return (MSR) mission, a sample canister launched from Mars will be autonomously captured by an orbiting satellite. We present the concept and the design of an active 3D camera supporting the orbiter navigation system during the rendezvous and capture phase. This camera aims at providing the range and bearing of a 20 cm diameter canister from 2 m to 5 km within a 20° field-of-view without moving parts (scannerless). The concept exploits the sensitivity and the gating capability of a gated intensified camera. It is supported by a pulsed source based on an array of laser diodes with adjustable amplitude and pulse duration (from nanoseconds to microseconds). The ranging capability is obtained by adequately controlling the timing between the acquisition of 2D images and the emission of the light pulses. Three modes of acquisition are identified to accommodate the different levels of ranging and bearing accuracy and the 3D data refresh rate. To come up with a single 3D image, each mode requires a different number of images to be processed. These modes can be applied to the different approach phases. The entire concept of operation of this camera is detailed with an emphasis on the extreme lighting conditions. Its uses for other space missions and terrestrial applications are also highlighted.

This design is implemented in a prototype with shorter ranging capabilities for concept validation. Preliminary results obtained with this prototype are also presented.

Improved performance LADAR receiver

B. Dion, N. Bélanger, J. Lauzon, M. Tremblay, CMC Electronics Inc. (Canada)

Preliminary data, to be updated once research activity will be completed...

Optical LADARs require high sensitivity near 1 nanowatt while having also fast recovery to overloads as high as 100W. Fast recovery is required in order to detect a secondary target from behind a bright target. In the current work, we have created a new family of LADAR receivers having a gain bandwidth product larger than most commercially available receivers. While maintaining the receiver bandwidth, a 4.8 time increase in responsivity can now be achieved. With cooling of the APD, these new receivers are offering more than 2 time reduction of the NEP, allowing longer range coverage of the LADAR system. In addition a new feature is accelerating the overload recovery to 93ns from an overload laser pulse of 56mW allowing nearby secondary target detection.

Compact 3D flash LIDAR video cameras and applications

R. Stettner, Advanced Scientific Concepts, Inc. (United States)

This paper will discuss the operation of ASC's newest compact 3D Flash LIDAR Video Cameras (3D FLVCs) and their solution to an increasing collection of technical problems. These solutions range from space shuttle docking to autonomous ground vehicle navigation. Figure 1 illustrates the ASC TigerEye 3D FLVC. The performance of this camera as well as

Figure 1. ASC TigerEye FLVC: 4"x 4"x 5" Convectively Cooled

other ASC 3D FLVCs will be discussed in terms of frame rate, resolution, range, power and form factor.

In July 2009 ASC and SpaceX successfully demonstrated ASC's DragonEye 3D Flash LIDAR ISS docking sensor in low earth orbit on STS 127, illustrating the utility and robustness of these compact 3D FLVC systems. Figure 2 shows the DragonEye (a version of the TigerEye) in the STS 127 Bay.

Figure 2. ASC's DragonEye 3D FLVC in the STS 127 bay.

NASA as well as a number of Aerospace firms are also evaluating ASC's 3D FLVCs for entry decent and landing on the moon and planets.

Currently 3D FLVCs are critical to the unmanned vehicle community, where 3D navigation must be performed in real time from a moving vehicle. Figure 3 shows one frame of a 3D movie taken from a moving automobile using an ASC 3D FLC where range and velocity to other objects can be determined.

Figure 3. Vehicle mounted 3D FLVC. Range to surrounding objects as well as their velocities can be easily calculated. The two images are really a single frame of data extracted from a 3D movie taken a 10 Hz; the right had side is rotated so the observer is above the scene and illustrates the three-dimensionality of the data.

The applications and data results illustrated in Figures 2 and 3 as well as many others will be discussed in detail in the paper.

7684-06, Session 4

3D range gated imaging in scattering environments

M. Laurenzis, F. Christnacher, D. Monnin, Institut Franco-Allemand de Recherches de Saint-Louis (France); I. Zielenski, Wehrtechnische Dienststelle für Waffen und Munition (Germany)

During the last decade ISL has worked on 3D imaging methods based on Gated Viewing. Usually, 3D information is obtained by tomography imaging i.e. sliding time-slice technology based on the post-processing of an immense number of images, recorded with different sensor gate delays. To reduce post-processing and acquisition time, ISL has developed a new Gated Viewing method working with a reduced number of images (minimum two images). This technique enables a super-resolution depth mapping through the analysis of two overlapping observation regions.

In the present paper, we investigated the performance of both methods (tomography and super-resolution depth mapping) in scattering environment. Fist experiments were carried out under determined laboratory conditions in a fog chamber. Further, field tests with the presence of smoke generators were performed on the ISL test facility. During these tests, we realized homogeneous and inhomogeneous scattering environments. Both conditions were representative for the application of 3D data acquisition in hostile environment (like underwater, forest fire, military missions). Due to the fact, that the investigated techniques depend on a pixel-wise intensity analysis, the presence of a scattering environment has impact on the depth resolution accuracy. This effect is a result of higher noise levels, obscuration and inhomogeneities.

7684-07, Session 4

3D-LZ helicopter ladar imaging system

J. C. Savage, Air Force Research Lab. (United States); B. Burns, H.N. Burns Engineering (United States); W. Harrington, Air Force Research Lab. (United States)

A joint-service team led by the Air Force Research Laboratory's Munitions and Sensors Directorates completed a successful flight test demonstration of the 3D-LZ Helicopter Ladar Imaging System. This was a milestone demonstration in the development of technology solutions for a problem known as "helicopter brownout", the loss of situational awareness caused by swirling sand during approach and landing. The 3D-LZ (three-dimensional landing zone) ladar was developed by H.N. Burns Engineering and integrated with the US Army Aeroflightdynamics Directorate Brown-Out Symbology Set (BOSS) aircraft state symbology aboard a US Army EH-60 Black Hawk helicopter. The combination of these systems provided an integrated degraded visual environment landing solution with landing zone situational awareness as well as aircraft guidance and obstacle avoidance information. Pilots from the US Army, Air Force, Navy, and Marine Corps achieved an unprecedented 70-80% landing rate in full brownout conditions at a test range at Yuma Proving Grounds, Arizona. This paper will focus on the ladar technology used in 3D-LZ and the results of this milestone demonstration.

7684-08, Session 4

Calibration targets and standards for 3D lidar systems

B. H. Miles, G. W. Kamerman, D. K. Fronek, P. Eadon, FastMetrix, Inc. (United States)

No abstract available

7684-09, Session 4

Spectral LADAR: toward active 3D multispectral imaging

M. A. Powers, General Dynamics Corp. (United States) and Univ. of Maryland, College Park (United States); C. C. Davis, Univ. of Maryland, College Park (United States)

We present our Spectral LADAR concept, an augmented implementation of traditional LADAR. This sensor uses a polychromatic source to obtain range-resolved 3D spectral images which can be used to identify objects based on combined spatial and spectral features in three dimensions and up to several hundred meters in distance. We report on a proof-of-concept laboratory demonstrator which generates spectral point clouds from static scenes. The Spectral LADAR demonstrator transmits nanosecond supercontinuum pulses generated in a photonic crystal fiber. Initially we use a rapidly tuned receiver with a high speed InGaAs APD for 30 spectral bands with the future expectation of implementing a linear APD array spectrograph. Each spectral band is independently range resolved with multiple return pulse recognition. This is a critical feature, enabling simultaneous spectral and spatial unmixing of partially obscured objects when not achievable using image fusion of monochromatic LADAR and passive spectral imagers. This enables higher identification confidence in highly cluttered environments such as forested or urban areas (e.g. vehicles behind camouflage or foliage). These environments present challenges for robotic perception and visual awareness which can benefit from the unique attributes of Spectral LADAR. Results from this demonstrator unit are presented for scenes typical of military operations and characterize the operation of the device. The results are discussed here in the context of autonomous vehicle navigation and target recognition.

7684-10, Session 4

Product chain analysis of three-dimensional imaging laser radar systems

N. A. Lopez, R. R. Burton, G. W. Kamerman, B. H. Miles, W. Crouch, FastMetrix, Inc. (United States)

No abstract available

7684-11, Session 5

The dawn of optical radar: a story from another side of the globe

V. V. Molebny, National Taras Shevchenko Univ. of Kyiv (Ukraine); P. Zarubin, State Unitary Enterprise V.K. Orlov Granat Development Bureau (Russian Federation); G. W. Kamerman, FastMetrix, Inc. (United States)

Some episodes are discussed about the development of the optical radar in one of the R&D institutes of the former Soviet Union which is Kvant Institute in Kiev, Ukraine. The story starts with the attempt to spot the submarine by its wake using the argon laser and coherent detection in sixties and the early design of the surveillance laser radar for navy developed in seventies with spatial suppression of the backscatter. Fire control systems, developed later, incorporated radar designation combined with a wide field-of-view laser radar, a range finder and a passive far infrared system based on multi-element linear array and mechanical scanning. Laser countermeasure systems initiated development of super-wide-angle laser threat detection and double-circuit tracking, as well as target recognition and classification according to its polarization parameters. Studies of speckle propagation in the atmosphere resulted in dual application of these studies: for speckle suppression and for selection of the fluctuating retroreflecting targets.

7684-12, Session 5

32 x 32 Geiger-mode LADAR camera

P. Yuan, R. Sudharsanan, X. Bai, J. C. Boisvert, P. A. McDonald, J. J. Chang, W. D. Hong, Spectrolab, Inc. (United States); S. Van Duyne, G. Pauls, S. D. Gaalema, Black Forest Engineering (United States)

For the wide applications of LAser Detection and Ranging (LADAR) imaging with large format Geiger-mode avalanche photodiode (APD) arrays, it is critical and challenging to develop a LADAR camera suitable to volume production with enough component tolerance and stable performance. Recently Spectrolab and Black Forest Engineering developed a new 32x32 Read-Out Integrated Circuit (ROIC) for LADAR applications. With a specially designed high voltage input protection circuit, the ROIC can work properly even with more than 1 % of pixels shorted in the APD array; this feature will greatly improve the camera long-term stability and manufacturing throughput. The Non-uniform Bias circuit provides bias voltage tunability over a 2.5 V range individually for each pixel and greatly reduces the impact of the non-uniformity of an APD array. A SMIA high speed serial digital interface streamlines data download and supports frame rates up to 30 kHz. The ROIC can operate with a 0.5 ns time resolution without vernier bits; 14 bits of dynamic range provides 8 µs of range gate width. At the meeting we will demonstrate more performance of this newly developed 32x32 Geiger-mode LADAR camera.

7684-13, Session 5

Intensified imaging photon-counting technology for enhanced flash LIDAR performance

C. J. Grund, A. Harwit, Ball Aerospace & Technologies Corp. (United States)

Intensified Imaging Photon Counting (I2PC) is a new approach to flash lidar that employs direct coupling of a photocathode and microchannel plate front end to a high-speed, pipelined, all-digital Read Out Integrated Circuit (ROIC) to achieve photon-counting temporal waveform capture in each pixel on each laser return pulse. A unique characteristic of this architecture is the absence of analog components that limit temporal resolution and dynamic range. When implemented in 65nm CMOS technology, the Ball I2PC design is expected to record up to 300 photon arrivals in each pixel with 100 ps resolution on each pulse return with up to 6000 range bins in each pixel. Additional advantages of this architecture are operation at any wavelength where photocathodes are available, intrinsically low f/# and high fill factor capability, array sizes to 3000X3000 pixels with available components, extremely high dynamic range, and extremely low false alarm rates. In addition to long-range and low-power hard target imaging, I2PC extends scannerless flash lidar potential to distributed target applications such as atmospheric remote sensing, vegetation canopies, and camouflage penetration. We discuss the I2PC architecture, development status, anticipated performance, advantages and limitations.

7684-14, Session 5

Foliage penetration obscuration probability density function analysis from overhead canopy photos gimbaled linear-mode and Geiger-mode airborne lidar

R. R. Burton, FastMetrix, Inc. (United States)

No abstract available

7684-15, Session 5

Foliage penetration characterization as a function of ground resolved distance and angular diversity for linear-mode and Geiger-mode airborne lidar

R. R. Burton, D. A. Kalin, N. A. Lopez, FastMetrix, Inc. (United States)

No abstract available

7684-16, Session 6

Passive cross-wind remote sensing using optical turbulence-induced fluctuations

O. Porat, J. Shapira, G. Machavariani, Soreq Nuclear Research Ctr. (Israel)

The atmospheric turbulence induces random irregularities in the index of refraction of the atmospheric medium. While propagating through these irregularities, optical wave-fronts become distorted since different sections of the wave-front go through different optical paths. These distortions cause wave-front propagation direction fluctuations, focusing and de-focusing effects, loss of coherency and irradiance fluctuations.

The case of imaging a naturally illuminated scene through the atmosphere is considered and a method for estimating the crosswind speed and direction from a video sequence is proposed. The method is based on spatial and temporal correlations of the intensity fluctuations induced by atmospheric turbulence. Main accent is made on the role of typical spatial scales of the turbulence and their variations as parameters of the scene and measuring device change: turbulence strength, imaging range, temporal and spatial resolution, etc. Results obtained from controlled field experiments using various cameras are discussed.

7684-17, Session 6

Atmospheric aerosol characterization using multiwavelength multistatic light scattering

A. M. Wyant, The Pennsylvania State Univ. (United States); C. R. Philbrick, North Carolina State Univ. (United States)

A scattering sensor for multiple wavelengths and multiple angles has been designed and is being tested for the characterization of atmospheric aerosols. The study has been performed using Mie theory to determine the optimal wavelengths and angles for the sensor design to best characterize typical atmospheric aerosols. Charge coupled device (CCD) imagers are used to record scattering measurements at two polarizations and as a function of angle relative to the co-aligned laser beams. A diffraction grating is used to spatially separate the wavelengths across the field-of-view of the CCD array; thus allowing simultaneous measurements at multiple wavelengths. Experiments are conducted to measure the scattering intensities for two polarizations at wavelengths that span the visible and near-infrared region. The data from the images are inverted using Mie theory to analyze and determine the aerosol properties of artificially generated smoke and natural fog. The results are compared with in situ measurements of aerosol properties along the path.

7684-18, Session 6

Optical remote sensing techniques to characterize the properties of atmospheric aerosols

C. R. Philbrick, North Carolina State Univ. (United States) and The Pennsylvania State Univ. (United States); H. D. Hallen, North Carolina State Univ. (United States); A. M. Wyant, The Pennsylvania State Univ. (United States); T. P. Wright, M. Snyder, North Carolina State Univ. (United States)

Several laser remote sensing techniques are used to characterize the properties of aerosols. The various techniques include: backscatter, optical extinction using Raman scatter, and bistatic/multistatic scattering using the polarization ratio of the scattering phase function. The number density, size, and size distribution are obtained under the assumption of spherical scatterers. Other measurements can be used to describe additional properties, such as aerosol type based upon approximate refractive index and detected departure from spherical, when simultaneous measurements at several wavelengths and several angles are analyzed. Examples are shown to demonstrate our present capability to characterize aerosol particles using recently developed techniques.

7684-19, Session 6

Lidar, TEOM, and sunphotometer measured and model reconstructed atmospheric parameters

D. Vladutescu, B. M. Gross, Y. Wu, F. Moshary, S. A. Ahmed, The City College of New York (United States)

With the dramatically climate changing we are facing today atmospheric monitoring is of major importance. Several atmospheric monitoring instruments are used for measuring atmospheric composition, optical coefficients, PM2.5, aerosol optical depth, size distribution, PBL height and many other parameters. However an inexpensive method of determining these parameters is by use of models and one model that depicts the aerosol dynamics in the atmosphere is the Community Multi-scale Air Quality (CMAQ) model. Our paper is focused on converting CMAQ retrieval outputs into optical coefficients that can then be comparing the lidar, AERONET and TEOM measurements performed at City College of the City University of New York . Differences between the full approach and parameterized methods such as the MALM formula used in AIR-NOW are observed and comparisons with AERONET show the full modeling is in general superior to the MALM formula.

Human activities affect the global climate and may affect the economic, social and political circumstances in the long term. The estimation of the contribution of the Earth's climate system components needs observation and continuous monitoring of various atmospheric physical and chemical parameters. Temperature, water vapor and greenhouse gases concentration, aerosol and clouds loads, and atmospheric dynamics are parameters of particular importance in this respect. The quantification of the anthropogenic influence on the dynamics of these above-mentioned parameters is of crucial importance nowadays but still affected by significant uncertainties.

In the present context of these huge uncertainties in our understanding of how these different atmospheric compounds contribute to the climate processes, our paper presents in the first part, the development of lidar (Light Detection and Ranging)-based remote sensing techniques for atmospheric monitoring and in particular the analyses of urban aerosol backscattering properties based on parametric coefficients and lidar measurements. These analyses exploit the aerosols hygroscopic properties and their interaction properties with light. The analyses presented here are based on the use the water vapor and aerosol backscatter measurements in the exploration of the nature and variability of urban aerosol hygroscopic properties using multi-wavelength Raman lidar measurements at 355nm, as well as backscatter measurements at 532nm and 1064nm. The addition of the longer wavelength channels

allows us to more accurately validate the homogeneity of the aerosol layer as well as provide additional multi wavelength information that can be used to validate and modify the aerosol models underlying the hygroscopic trends observed in the Raman Channel.

The traditional method of investigation of the relationship between aerosol scattering and RH (relative humidity) was to use humidified nephelometer. However, at high RH this instruments are hard to control and therefore alternative methods have been investigated. One of these methods is using lidar measurements [1,5] for RH>85% to probe behavior of hygroscopic growth.

Unfortunately, direct comparisons would require detailed measurements of the microphysical properties of the aerosol for a given event. Therefore, In the second part of the paper we focus on using CMAQ data as a better estimate of the aerosol properties and therefore must assess CMAQ outputs. This is done using lidar, sunphotometer and TEOM measurements performed at the CCNY campus which is located at -73.96° west longitude and 41.8° north latitude. The parameters obtained from the multiwavelength Raman lidar are the backscatter at 355nm, 532nm and 1064nm and extinction at 355nm. The data used for comparison is sparse due to unfavorable atmospheric conditions like rain or low clouds that do not allow for correct alignment of the lidar system or data collection with trhe sky radiometer. Therefore we performed extensive analysis over the following days: November 21st, 2008; December 8th 2008; January 21st and 23rd of 2009. The CMAQ model provided mass concentration for different species and size modes alongside with pressure, water vapor and temperature at 22 different layers between surface and 16000 m. This data allowed for calculation of the optical parameters taking into consideration the hygroscopic growth based on the relative humidity (RH) at the corresponding levels. The growth factor and the refractive index for the different species and wavelengths were obtained from the Optical Properties of Aerosols and Clouds (OPAC) data base. After retrieving the extinction and backscatter for each mode and species we added up the results and compared with the lidar mie channels: 355, 532nm and 1064nm. A vertical integration of the extinction coefficients also allowed for aerosol optical depth (AOD) comparison with the sunphotometer measurements. To complete the comprehensive validation of the CMAQ model we also compared the concentrations of particulate matter less than 2.5um in diameter measured by the TEOM instrument located on the CCNY campus.

7684-20, Session 6

Standoff detection of explosives in open environment using EPF

T. Arusi-Parpar, S. Fastig, A. Englander, J. Shapira, B. Shwartzman, D. Rubin, Y. Ben-Hamo, Soreq Nuclear Research Ctr. (Israel)

Stand-off detection of explosives by PF (Photodissociation Fluorescence) method was shown to be effective for detection of nitro-containing explosives with relative high vapor pressures such as TNT. Soreq NRC has successfully demonstrated this method with a laboratory system at ambient conditions with sensitivity of ~ 1 ppb-m. However, the ppb-m level detection sensitivity is not sufficient for stand-off detection of other common NO containing explosives, such as RDX, PETN and SEMTEX due to their significantly lower vapor pressure

By applying remote vapor enhancement of the explosive traces through irradiation of the target using an IR laser, detection sensitivity is significantly enhanced. An improvement of at least three orders of magnitude was achieved.

Here we present an experimental Enhanced-PF (EPF) system operating in a stand-off detection mode, outside the lab in field-like conditions. The transmitter consists of a tunable, narrow-band excimer laser, a telescope and steering optics. The receiver consisted of a 30 cm collecting telescope, custom designed spectral filters and a solar blind photomultiplier. This enhanced system has successfully demonstrated remote detection of explosives such as RDX, PETN, C4, and SEMTEX like materials whose ambient vapor pressures are three to four orders of magnitude lower as compared to TNT. Even mixed explosives such as 1%TNT and 10%RDX in sand have been successfully detected.

Experimental results will be presented and tradeoffs of this method will be discussed.

7684-21, Session 6

Wind turbine load reduction and AEP improvement via lidar

J. Wu, GE Global Research (United States)

Commercially available light detection and ranging (lidar) systems are challenged by high system cost, low spatial resolution, slow data refresh rates, and are subject to environmental interference. A new lidar technology presented in this paper enables a wind anemometer with substantially lower cost, higher spatial resolution, and faster data refresh rates, all of which are ideal for real-time wind speed and direction monitoring when mounted as part of a singular wind turbine.

A recent study conducted by GE has shown that, incorporation of such a lidar with optimized turbine control can improve the wind turbine Annual Energy Production (AEP). Additional benefits include reduced turbine fatigue and increased lifetime through proactive load reduction.

7684-22, Session 7

The application of iterative closest point (ICP) registration to improve 3D terrain mapping estimates using the FLASH 3D LADAR system

E. E. Armstrong, OptiMetrics, Inc. (United States); J. Woods, Air Force Research Lab. (United States); W. Armbruster, FGAN-FOM (Germany); R. Richmond, ITT Advanced Engineering & Sciences (United States)

The primary purpose of this research was to develop and effect means of creating a 3D terrain map image (point-cloud) in GPS denied regions from a sequence of co-bore sighted visible and 3D LIDAR images. Both the visible and 3D LADAR cameras were hard mounted to a vehicle. The vehicle was then driven around the streets of an abandoned village used as a training facility by the German Army and imagery was collected. The visible and 3D LADAR images were then fused and 3D registration performed using a variation of the Iterative Closest Point (ICP) algorithm. The ICP algorithm is widely used for various spatial and geometric alignment of 3D imagery producing a set of rotation and translation transformations between two 3D images. ICP rotation and translation information obtain from registering the fused visible and 3D LADAR imagery was then used to calculate the x-y plane, range and intensity (xyzi) coordinates of various structures (building, vehicles, trees etc.) along the driven path. The xyzi coordinates information was then combined to create a 3D terrain map (point-cloud). In this paper, we describe the development and application of 3D imaging techniques (most specifically the ICP algorithm) used to improve spatial, range and intensity estimates of imagery collected during urban terrain mapping using a co-bore sighted, commercially available digital video camera with focal plan of 640x480 pixels and a 3D FLASH LADAR. Various representations of the reconstructed point-clouds for the drive through data will also be presented.

7684-23, Session 7

Super-resolution enhancement of FLASH LIDAR data

A. Bulyshev, Analytical Mechanics Associates, Inc. (United States); G. D. Hines, M. D. Vanek, F. Amzajerdian, R. Reisee, NASA Langley Research Ctr. (United States)

Flash LIDAR technology is evaluated as the prime tool for safe, precision soft-landing in future robotic and crewed lunar and planetary missions.

The ability of the Flash LIDAR to generate 3-dimensional maps of the landing site area during the final stages of the descent phase for detection of hazardous terrain features such as craters, rocks, and steep slopes is under study in the frame of the Autonomous Landing and Hazard Avoidance (ALHAT) project. It has been found that a single frame of existing FLASH LIDAR systems is not sufficient to build a map of entire landing site with acceptable spatial resolution and precision of the elevations detection. One way to overcome this obstacle is using a super-resolution approach. In this paper a new super-resolution algorithm in application to FLASH LIDAR data is proposed. The major goal of this algorithm is to create a Digital Elevation Map covering a sufficiently large area and with acceptable accuracy and precision. Performance of the super-resolution algorithm has been analyzed through a series of simulation runs utilizing a high fidelity Flash LIDAR model and a high resolution synthetic lunar elevation map. For each simulation run, a sequence of FLASH LIDAR frames is recorded and processed as the spacecraft descends toward the landing site with different trajectory profiles having varying LIDAR look angle of the terrain. The results show that achieved level of accuracy and precision in generating an elevation map of the landing site is adequate for detecting hazardous terrain features and identifying safe areas.

7684-24, Session 7

Redundancy analysis of raw Geiger-mode laser radar data

N. A. Lopez, G. W. Kamerman, FastMetrix, Inc. (United States)

No abstract available

7684-25, Session 7

Scene-based algorithm for range/intensity estimation correction for the FLASH 3D LADAR system

S. Jordan, Air Force Research Lab. (United States); E. E. Armstrong, OptiMetrics, Inc. (United States); H. Larson, Swedish Defence Research Agency (Sweden); M. J. Gebhardt, Air Force Research Lab. (United States); O. Steinvall, Swedish Defence Research Agency (Sweden)

In many laser radar systems the intensity value's strength is dependent on the reflectivity on the measured surface. High intensity values are necessary for accurate range measurements. When measuring a low-reflectivity surface the returning laser intensity will be low. This, in turn, results in high uncertainty in the range estimate. In this paper, an approach to correct the intensity values are presented, which results in more accurate range estimates even on low-reflecting surfaces.

Examples are shown using the ACS (Advanced Scientific Concepts) FLASH 3D LADAR sensor. During a measurement campaign several series of measurements characterizing the shape of the return laser pulse from surfaces with known reflectivity was performed. Using principal components analysis (PCA), variation in pulse shape as a function of laser intensity was determined. These data were then used to identify a parametric model that described the variation in intensity values relative to the surface's reflectivity. Based on the model, an approach to systematically adjust intensity values has been developed. In this paper, we will also examine laser timing jitter and intensity and its effects on range estimation.

7684-26, Session 7

Signal processing on waveform data from the Eyesafe Ladar Testbed (ELT)

K. D. Neilsen, S. E. Budge, R. T. Pack, Utah State Univ. (United States)

The Eyesafe LADAR Test-bed (ELT) is a raster scanning, single-beam, energy-detection LADAR. With the capability of digitizing and recording the return pulse waveform at 2 GHz in the field for off-line 3D point cloud formation research in the laboratory, the ELT serves as a prime tool in understanding the behavior of LADAR waveforms. Signal processing techniques have been applied to the ELT waveform in an effort to exploit the signal with respect to noise reduction, range resolution improvement, and ability to discriminate between two surfaces of similar range.

This paper presents a comparison of the results of the digital signal processing techniques used on the ELT waveform. These include several types of filtering, interpolation, and deconvolution. Significant improvements in range error and range resolution are reported for the various techniques investigated.

7684-27, Session 7

Automated in-track and cross-track airborne flash LADAR image registration for wide-area mapping

C. M. Wong, J. E. Logan, C. Bracikowski, B. K. Baldauf, Northrop Grumman Aerospace Systems (United States)

No abstract available

7684-29, Session 8

Coherent high-resolution sparse aperture imaging test bed

I. Anisimov, P. F. McManamon, D. Shemano, N. J. Miller, Ladar and Optical Communications Institute (United States); J. W. Haus, Univ. of Dayton (United States)

Coherent high resolution imaging of distant targets is a very complex problem that involves understanding of diffractive properties of the optical imaging system, statistical properties of the atmospheric refractive index variations, coherence properties of the light source etc. In coherent laser radar imaging system, the target is illuminated with the laser beam, and the returned from the target light wave is referenced to the light wave from the same source. Such system is referred to as spacial heterodyne imaging system. The sparse aperture imaging approach is based on reducing the total radiation intensity collection area using smaller subapertures, while the resulting resolution of the sparse aperture imaging system is equivalent to a larger single aperture. Ladar and Optical Communications institute (LOCI) is currently building a prototype of the high resolution sparse aperture imaging testbed in collaboration with industry partners, academic institutions, and the government. This testbed will become an innovative research tool in the field of high resolution coherent ladar imaging.

7684-30, Session 8

Compact diode laser homodyne vibrometers

C. J. Grund, LightWorks LLC (United States); H. Guenther, J. C. Connolly, Innovative Photonic Solutions (United States)

We discuss the architecture and performance of compact, robust, alignment-free, homodyne vibrometers using telecom diode lasers as the illumination source. The technical challenges and performance of implementations using conventional macroscopic optical components are compared with ultra-miniature micro-bench components and assembly methods. Focused sensitivity exceeding 20 pm/SQRT(Hz) at 1m range, 36 pm/SQRT(Hz) at 5m range, and useful operation to >20m have been demonstrated with COTS 1550 nm sources, 1.5 cm transmit/receive beam diameter and 32 mW transmitted power. Vibrometer measurement bandwidth exceeds 100 kHz with current electronics. Demonstrated performance is suitable for a variety of defense, security, and inspection applications.

7684-31, Session 8

Matched-filter CNR and diversity for deterministic and random coherent ladar signals

P. Gatt, D. Jacob, Lockheed Martin Coherent Technologies (United States)

No abstract available

7684-65, Session 8

A history of laser radar development in the United States

P. F. McManamon, Exciting Technology, LLC (United States); G. W. Kamerman, FastMetrix, Inc. (United States)

No abstract available

7684-33, Session 9

Feature extraction using voxel aggregation of focused discrete LIDAR data

S. Hagstrom, D. W. Messinger, S. D. Brown, Rochester Institute of Technology (United States)

The ability of multiple-return airborne lidar systems to resolve fine details has grown significantly since their introduction, and many modern instruments are capable of footprint sizes under a half meter. Because most systems scan at near-nadir angles, the pulse origin is often ignored and not recorded with the return point cloud data. By recording this additional position information over multiple focused collects we show how properties such as occlusion can be derived using voxel aggregation of the return data. The voxel map allows us to exploit this new information in scenes with significant spatial structure, such as under tree canopies. Results are presented which show the accuracy of our approach under canopies of varying occlusion levels. Our findings are validated using simulated data provided by the Rochester Institute of Technology through the DIRSIG software. DIRSIG (Digital Imaging and Remote Sensing Image Generation) is a first principles based synthetic image generation model which has the capability to produce full waveform lidar signals from artificially created scenes.

7684-34, Session 9

Three-dimensional transformation for automatic target recognition using LIDAR data

R. D. Nieves, W. D. Reynolds, Jr., ITT Corp. (United States)

The three-dimensional (3-D) nature and the unorganized structure of 3-D LIDAR data pose several challenges for target recognition tasks. In the

past, several approaches have applied two-dimensional transformations such as spin-images or Digital Elevation Maps (DEMs) as an intermediate step for analyzing the 3-D data with two-dimensional (2-D) methods. However, these techniques are computationally intensive and often sacrifice some of the overall geometrical relationship of the target points.

In this paper, we present a simple and efficient 3-D spatial transformation that preserves the geometrical attributes of the LIDAR data in all its dimensions. This transformation permits the utilization of well established statistical and shape-based descriptors for the implementation of an automatic target recognition algorithm. We evaluate our transformation and analysis technique on a set of simulated LIDAR point clouds of ground vehicles with varied obstructions and noise levels. Classification results demonstrate that our approach is efficient, scale invariant, rotation invariant and robust to noise and other degradations.

7684-35, Session 9

Laser gated viewing: an enabler for automatic target recognition?

E. G. P. Bovenkamp, K. Schutte, TNO Defence, Security and Safety (Netherlands)

For many decades attempts for Automatic Target Recognition has been made using both visual and FLIR camera systems. A recurring problem area in these approaches is the segmentation problem, that is the separation between the target and its background.

This paper describes an approach to Automatic Target Recognition using a laser gated viewing system. Here laser-flash illumination is used combined with a gating viewer such that only a small part in the distance domain is seen in a single image. In our approach, using a Intevac LIVAR imaging system, we combined several images with different gate settings to construct a 3D data cube. The paper describes the preprocessing and filtering steps taken to obtain a range image, that is an image where each pixels' value is its distance to the camera. A depth segmentation is performed based on the global histogram of this range image. After this depth segmentation a very good segmentation is obtained. Based upon this segmentation, classification results will be given for persons and vehicles. An outlook will be given towards operational application of this procedure.

7684-36, Session 9

Obstruction detection via small-footprint full-waveform LADAR for mobility applications

A. L. Neuenschwander, L. A. Magruder, The Univ. of Texas at Austin (United States)

Laser Radar, also referred to as ladar, has become widely available and is an established contributor to the military and intelligence community by providing precise elevation data using 3-dimensional measurements. The utilization of customized algorithms designed for full-waveform ladar 3-D surface modeling has provided the capability to detect among obscurants and resolve the underlying topography despite canopies or camouflage. These capabilities lend themselves as tools for mapping trafficability and mobility assessments, producing significant information with regard to geospatial information and battlespace preparation. Elevations derived from a small-footprint full-waveform laser system were mapped into voxels above the ground surface. A tree finding algorithm was employed to identify trees and subsequently predict obstructions due to the presence of tree trunks. Based on the elevation voxels, potential open zones (and conversely, obstructions) based on width, height, and slope of neighboring pixels were mapped. Several realizations of width and height were implemented to simulate scenarios of mobility for vehicles beneath canopy.

7684-37, Session 10

Simulating full-waveform LIDAR

A. M. Kim, R. C. Olsen, C. Borges, Naval Postgraduate School (United States)

A Monte Carlo model of laser propagation through a tree is presented which allows simulation of full-waveform LIDAR signatures. The model incorporates a LIDAR system and a 'natural' scene, including an atmosphere, tree and ground surface. The PROSPECT leaf reflectance model is incorporated to determine leaf properties. Changes in the scene such as varying ground reflectance, sloped vs. flat ground, and tree 'leaf-on' vs. 'leaf-off' conditions are analyzed. Changes in the LIDAR system are also studied, including laser wavelength, shape and length of transmitted pulses, angle of transmission, etc. Results of the simulations and analysis of the effects of physical changes in the scene and sensor are presented.

7684-38, Session 10

Receiver-operating characteristic for several multiple hypothesis range-rate filter algorithms

D. G. Youmans, SPARTA, Inc. (United States)

During initial acquisition of a target, the range and angle to the target are not precisely known. Therefore, the returns cannot be added together with perfect registration for increasing signal-to-noise ratio and (theoretically) increasing the probability of detection were this done. Several multiple-hypothesis range-rate (MH-RR) algorithms are discussed in this paper. The probability density functions and the statistics for these algorithms are developed so that one may determine the probability of detection versus false alarm rate.

7684-39, Session 10

Accuracy and exploitation of multilook lidar

M. Brown, M. W. Roth, E. Weidaw, J. Comer, D. Chilcott, The Johns Hopkins Univ. Applied Physics Lab. (United States)

No abstract available

7684-40, Session 10

Information theoretic comparison of Geiger-mode and linear-mode APDs for low-power LADAR systems

G. M. Williams, Jr., Voxtel, Inc. (United States)

High-speed, single-photon-sensitive two-dimensional avalanche photodiode (APD) focal plane arrays (FPAs) are in development for emerging small-sized, low-power laser radar (LADAR) systems. In the past, it has generally been necessary to operate near infrared (NIR) APDs in Geiger mode (Gm) to perform photon counting functions. However, a variety of linear-mode (lm) APDs are now being developed. Whereas GmAPD FPAs benefit from relatively simple pulse detection circuitry, they have limited detection efficiency (DE), very poor dark count rates (DCRs), and afterpulsing; these limit their capability to a single binary return per pulse frame. Unlike GmAPDs, which have a significant dead time (10 µs), lmAPDs can record the amplitude and time of arrival of the entire LADAR return, with no "temporal blindness," at the expense of more demanding amplifier circuitry.

An information theoretic approach will be used to explore the tradeoffs in size, weight, and power presented by the GmAPD and lmAPD FPA technologies. A discussion of the equivalent optical aperture of several

engagement scenarios will be considered as a function of the two FPA technologies' DE, DCR, signal-to-noise, and frequency response.

7684-41, Session 10

Physical modeling of 3D and 4D laser imaging

D. Hamoir, L. Hespel, G. Anna, F. Lafay, N. Rivière, B. Tanguy, ONERA (France)

Laser imaging offers potential for observation, for 3D terrain-mapping and classification as well as for target identification, including behind vegetation, camouflage or glass windows, at day and night, and under all-weather conditions. First generation systems deliver 3D point clouds from scanning threshold-detection telemetry. Threshold detection on the received signal is largely affected by the local opto-geometric characteristics of the objects of interest, leading to inaccuracies in the distances measured, and by partial occultation, leading to multiple echos. Second generation systems intend to circumvent these limitations by recording the waveforms received by the system after interaction with the environment, so

that data processing can be applied in order to improve the telemetry and the point cloud better match the reality. In the future, automatic target recognition algorithms may exploit the full potential of the 4D full-waveform data. Hence, being able to simulate point-cloud (3D) and full-waveform (4D) laser imaging is key. We have developped a numerical model for predicting the output data of 3D or 4D laser imagers. The model does account for the temporal and transverse characteristics of the laser pulse (i.e. of the "laser bullet") emitted by the system, its propagation through turbulent and scattering atmosphere, its interaction with the objects present in the field of view, and the characteristics of the optoelectronic reception path of the system.

7684-57, Poster Session

Statistical comparison between Hysplit sounding and lidar observation of planetary boundary layer characteristics over New York City

C. M. Gan, Y. Wu, B. M. Gross, F. Moshary, S. A. Ahmed, The City College of New York (United States)

The need to characterize in a robust way Planetary Boundary Layer (PBL) heights is crucial as in air quality forecast and transport models. In particular, incorrect determination of PBL heights can severely distort the surface air quality predictions such as PM2.5. Local properties and morphological features can influence PBL dynamics through local circulation phenomena such as the sea-breeze development as well as influences from the Urban Heat Island Canopy resulting in multiple layers that need to be resolved.

In this paper, based on a combination of wavelet and image processing methods, we develop methods to quantify multilayer PBL's and assess their dynamics with meteorological measurements including temperature, wind and humidity profiles. In particular, meteorologically based PBL heights based on both the Potential Temperature Gradient and Richardson Number are compared against both lidar derived and SODAR measurement and it is shown that in general, the Potential Temperature Gradient method is far better correlated to the PBL dynamics. Meanwhile, Hysplit model provide sounding data which can be used for comparison between actual sounding and lidar measurements. On the other hand, when strong atmospheric instability is present or layering develops, the comparison between different methods can provide information about the PBL internal structure. This information is useful in understanding the urban heat island and meteorology models. Further comparisons with air quality models such as CMAQ are also made and illustrate the difficulty in these models properly predicting the PBL dynamics seen in urban areas.

7684-58, Poster Session

Atmospheric cross-wind and turbulence measurements using turbulence-induced scintillations

J. Shapira, O. Porat, M. Livneh, Z. Wies, D. Heflinger, Y. Glick, G. Machavariani, A. Engel, Soreq Nuclear Research Ctr. (Israel)

We report remote measurements of cross-wind and atmospheric turbulence, using a one-station scheme. The experiment was performed over a flat beach parallel to the Mediterrian sea shore. Four white-screen diffusive targets were placed at distances 300, 600, 900 and 1200 m. Five anemometers were placed along the laser beam path, one near each target and at the measurement station. Each target was illuminated with a beam from a glass fiber pulsed infrared laser with a repetition rate of several thousand Hz and a sub-microsecond pulse-length, and output beam divergence of ~300 uRad. The receiver has the entrance aperture of 80 mm, and the incoming radiation is focused into an array of four 50x250um InGaAs detectors by a lens with f=280mm.

As most of remote wind-sensing methods, our method is based on observing the drift of scintillation pattern across the line of sight. The scintillations are caused by naturally- occurring turbulence-induced refractive index irregularities in the atmosphere, which drift at wind speed. Analyzing spatial-temporal cross-correlation function of the signals of two elements in the array, it is possible to obtain the cross-wind speed [1, 2]. We use zero-crossings technique for measuring the cross-wind value, while the cross-wind direction is determined from comparing areas from both sides from the peak of the cross-correlation function [3]. Here we present results obtained by these techniques in comparison to independent measurements of the anemometers. The results show good agreement. From the fluctuations of the signal on the detector array, our system measures also turbulence structure parameter Cn2, using angle-of arrival technique. The obtained results show reasonable agreement with independent scintillometer measurements of Cn2, performed with a CW He-Ne laser in two-stations setup with a detector at distance 60 m.

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[2] L. P. Poggio, M. Furger, A.S.H. Prevot, W.K.Graber, E.L.Andreas, J. of Atm. and Oceanic Tech., 17, 17-26 (2000).

[3] J. Shapira, H. Zmora, "FCS using LIDAR", patent PCT/ IL 2004/ 001039, November 2003.

7684-59, Poster Session

Developing a LIDAR for cross-wind profile measurements using turbulence-induced scintillations

G. Machavariani, J. Shapira, U. Talmud, O. Porat, S. Fastic, Soreq Nuclear Research Ctr. (Israel)

We report the developing of a prototype lidar for remote measurements of cross-wind profile, using backscattering from aerosol in a single-ended scheme. The system contains a pulsed Nd:YAG laser with 500 Hz repetition rate and ~20 nsec pulse width, as a transmitter, and a matrix of 8 detectors, placed at the focus of Cassegrain-type telescope, as a receiver. To realize detection of signals with high-sampling resolution, a high-sampling-rate digitizer with 8 simultaneously sampled channels and 60 MSamples/sec-per-channel sampling rate was incorporated into the system. Both mono-static and bi-static schemes with different parallaxes and different orientations of the detector matrix were evaluated theoretically and tested experimentally. The signal shape, estimated in a mono-static scheme using lidar equation and calculated geometrical form factor, was found to be similar to the experimentally obtained signal shape.

To check the ability to detect a local cross-wind flow, we performed an experiment using the cooling tower of Soreq reactor as a vertical wind

simulator. We recorded the detector signals from aerosol scattering at different distances, and analyzed the temporal-spatial cross-correlation function. The analysis of the asymmetry and shift of the cross-correlation function shows good ability for detecting of local cross-wind flow and allows qualitative mapping of the air flow. Next development steps will include improvement of the electronic circuits, in order to increase the sampling resolution along the line of sight, performing of additional controlled experiments and developing of wind-profile algorithm.

7684-60, Poster Session

Online primitive feature extraction from LIDAR range data for pose estimation and registration in a vehicle augmented reality system

R. B. Morrison, Naval Postgraduate School (United States)

Light Detection and Ranging (LIDAR) devices are increasingly used for mapping the environment in autonomous navigation and augmented reality systems. One difficulty is the estimation of the exact pose of the system without prior knowledge of the environment. Fiducial markers can be placed in the environment to provide a means of pose estimation and registration.

This paper discusses potential three dimensional primitive feature extraction algorithms to detect fiducial markers in LIDAR range data and the suitability of various 3D geometries for their use as fiducial markers. In related work, 2D high contrast markers have been used to register augmented reality imagery with the environment and vertical cylinders have been used for pose estimation of a ground-based LIDAR used to autonomously dock a wheelchair. For this work, a Velodyne HDL-64E S2 LIDAR was used for range data capture in street environments. Primitive features such as lines, arcs, and simple polygonal surfaces were extracted from the data and compared for fit to an a priori model of the fiducial marker. The system estimated fiducial locations were then compared with actual fiducial locations for accuracy and precision. Finally, there is a discussion of follow on work to use the fiducial markers to register the LIDAR three dimensional data with spherical camera image data.

7684-61, Poster Session

UV-IR combined LIDAR system

S. Fastig, Y. Ehrlich, S. Pearl, E. Naor, Y. Kraus, T. Inbar, D. Katz, Soreq Nuclear Research Ctr. (Israel)

Long range, combined UV-IR LIDAR system was built and tested. The system was developed to operate as a multi-wavelength DIAL in the IR (8-11 µm), dual wavelength excited LIF LIDAR in the UV, and aerosol map and track at 1.5 µm. The IR transmitter is a continuous tunable solid-state Tandem Optical Parametric Oscillator (OPO). The first OPO stage generates the 1.5 m beam and the second OPO stage pumped by the first, generates the IR band. In the UV the transmitter generates and transmits either the 266 nm or the 355 nm wavelengths sequentially. All the outgoing laser beams are pre-aligned to ensure geometric overlap of the measured paths. Energy reference is measured for each beam on every pulse. The receiver is based on a single reflective telescope with coatings optimized for both the UV and the IR. The optical signal is routed between the different detection packages by means of a computerized optical scanner mirror. The receiver-transmitter layout is based on periscope geometry and is equipped with a large - scanner. Computer control enables fast switching between the different measurements and wavelengths, data acquisition and spatial scan as well. The system was built in a mobile trailer and was field tested. Design consideration, preliminary results of subsystems and system performance in field experiments to measure and discriminate aerosol types, will be presented

7684-62, Poster Session

Accuracy study on 3D laser scan in establishing model of building

Y. Shi, X. Cheng, Tongji Univ. (China)

Three-dimensional laser scanning is a new type of non-contact acquisition method that obtains the three-dimensional surface data and color information of the object, which plays a very important role in the process of reconstructing three-dimensional digital models of the large building. In this paper, on the basic of a series of experimental studies, we analyze the point accuracy of three-dimensional laser scanning influenced by the internal factors and external environment, and the results show that the scanning distance error increases with the distance increasing; the angle, reflecting surface and environmental factor are not main sources of error, and the point error is mainly caused by the instrument itself. Due to the existence of registration error that converting the point cloud data of different positions to the coordinate system , we analyses the registration error under the condition of both complete targets as control point and non-target , and the aim is to study their adaptation to different condition, and to analyze reliability factors that influence the quality of the scanning data caused by the registration error. Take a example of Wenyuan Floor, and after the below steps: data collection, point cloud denoising, data registration, mesh generation and texture mapping et., we get the three-dimensional model of Wenyuan floor. We compare that mode with the measured CAD three-dimensional model with the use of the high accuracy total station, and analyze the existing advantages and deficiencies that the terrestrial laser scanner applies on the three-dimensional model reconstruction of the large buildings.

7684-63, Poster Session

Flash trajectory imaging of three-dimensional target motion

X. Wang, Y. Zhou, S. Fan, J. He, H. Liu, Y. Liu, Institute of Semiconductors (China)

Three-dimensional motion parameters determination and imaging of moving targets have been research hotspots in recent years. In defense and security, tracking targets, predicting the future position and giving their terminal parameters are very important. Traditional trajectory prediction technique and corresponding imaging processing are complicated, especially for targets in complex background. In order to solve the above problems, we present a flash trajectory imaging technique (FTIT) of three-dimensional target motion. This technique uses a pulse laser to illuminate targets and a camera with a microchannel plate to take images. The microchannel plate acts as both an amplifier and a shutter. In the FTIT, multi gating per frame and time slicing are used. For moving targets, the manner of multi gating per frame increases information of one single frame image so that one can directly gain the moving trajectory. Time slicing gives the range of targets and realizes silhouette detection which can directly extract targets from complex background. Therefore, the complexity of moving target image processing decreases. By one frame or two continuous frames, the motion parameters and flight attitude can be given. Since the minimum gating rate per frame is one and the maximum can reach several millions, the FTIT can image low or high speed moving targets and also give their 3D motion parameters. In addition, the manner of time slicing makes the FTIT has properties such as high suppression of backscatter from fog and other obscurants, high signal-to-noise ratio, and long detection range. For the FTIT, we have researched it in experiments and also studied the algorithm about it. Our research demonstrates that the FTIT is an effective way to gain the motion parameters of 3D motion targets. It gives a new method for 3D motion parameters determination and imaging of moving targets.

7684-42, Session 11

Calibration of a seafloor microtopography laser high-definition profiler

N. P. Chotiros, K. R. Loeffler, T. N. Nguyen, The Univ. of Texas at Austin (United States)

A two-step method for calibrating a laser high definition (HD) profiler is presented. The profiler consists of laser line sources and a HD video camera, and it is designed to be deployed on a remotely operated vehicle (ROV) for purpose of measuring small-scale seafloor topography. The system consists of a HD digital video camera and an arrangement of six green laser line generators. Each line generator contains a 5 mW green laser and a cylindrical lens to spread the beam into a plane. The laser planes are arranged to be parallel and vertical. The intersection of these planes with the seafloor creates profiles of the local topography that are recorded by the digital camera and processed to form a topographical map of the covered area. The calibration process is accomplished in two steps. First, distortions in the digital imager were measured using images of a test grid, and corrected by an interpolation method based on a virtual pinhole camera model. Then, the equations of the laser planes were determined according to their intersections with a target of known geometry and orientation, as imaged by the video camera. The target position and orientation were obtained by a registration process using only the video camera images. Work supported by the Office of Naval Research, Ocean Acoustics Program.

7684-44, Session 11

1.5-μm range gated imaging of small surface vessels

O. Steinvall, Swedish Defence Research Agency (Sweden); R. L. Espinola, U.S. Army Night Vision & Electronic Sensors Directorate (United States); M. Elmquist, K. Karlsson, Swedish Defence Research Agency (Sweden)

Within the framework of the NATO group (NATO SET 132 RTG 72) on imaging ladars, a test was performed to collect simultaneous multi-mode LADAR signatures of maritime objects entering and leaving San Diego Harbor. Beside ladars, passive sensors were also employed during the test which occurred during April 2009 from Point Loma and the harbour in San Diego.

This paper will report on 1.5 μm gated imaging on a number of small civilian surface vessels with the aim to present performance of passive and active imaging and to compare with the imaging performance models developed by US Army RDECOM CERDEC NVESD. We use controlled human perception tests to measure target identification performance and compare the experimental results with model predictions.

In the passive mode (using solar illumination) the noise due to speckles are eliminated and the influence by scintillation limited. In the active mode on the other hand these noise sources are present to a varying degree due to how many separate frames that have been averaged. We also compare day time and night time performance of the active mode showing how noise is reduced due to less scintillation during nigh time. Examples of increased performance in the active mode for strong solar direct illumination due to the elimination of shadows are presented.

7684-45, Session 12

Flight test results of an integrated dual airborne laser scanner (DALS)/INS navigator

M. Uijt de Haag, A. K. Vadlamani, Ohio Univ. (United States)

This paper discusses the flight test results of an integrated dual airborne laser scanner (DALS)/inertial navigation system (INS) navigator onboard Ohio University's DC-3 aircraft over Athens, Ohio. The use of two

airborne laser scanners (DALS), integrated with an INS form an alternative means of navigation in non-GPS and unknown terrain environments. In these environments the usual integration of GPS and INS will no longer be a viable option. This paper will address both a loose and tightly coupled method with and without an available terrain database and show low-level flight results.

7684-46, Session 12

From long range to high precision: pushing the limits of pulsed-time-of-flight measurement

M. Pfennigbauer, RIEGL Laser Measurement Systems GmbH (Austria); B. Möbius, Jena-Optronik GmbH (Germany); A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria); J. Pereira do Carmo, European Space Research and Technology Ctr. (Netherlands)

We present experimental results on two breadboard systems developed within ESA contracts dealing with a long-range rendezvous and docking sensor on one hand and high precision relative attitude control sensor on the other. A rendezvous and docking sensor to be used in a Mars sample return mission has been developed and recently tested over a range of 5 km. A high-speed 3-D laser scanner with range noise below 1 mm was realized and demonstrated. A critical assessment of the performance and potential for further developments of both systems is given.

7684-48, Session 12

A novel NLFM waveform generator using tunable integrated optical ring resonators

D. B. Adams, W. T. Snider, C. K. Madsen, Texas A&M Univ. (United States)

The NLFM waveform resulting from a tunable integrated optical ring resonator is simulated and compared with the well known tan-FM waveform. The metrics of interest are the first sidelobe levels and FWHM times of the autocorrelation, as these directly relate to the long-range performance and fine range resolution of a LADAR system, and should ideally be as small as possible. Through simulation, the sidelobe level of the autocorrelation of an NLFM waveform generated by a series of tunable integrated optical ring resonators is shown to be lower than the autocorrelation sidelobe level of an equivalent optimized tan-FM waveform with an equal FWHM time.

7684-49, Session 12

High-power high-rep-rate SLM lasers

J. P. Kilmer, G. Ross, Y. Yin, Photonics Industries International, Inc. (United States)

Single Longitudinal Mode (SLM) lasers are of interest for various coherent LIDAR techniques that utilize the Doppler wavelength shifting effect. Also, narrow linewidth lasers are of interest for Differential Absorption LIDAR (DIAL) which can precisely identify trace chemical species. However, such SLM lasers are often limited to low (~100Hz) rep rates due to laser seeding limitation. We report the development of a seeded SLM technology that enables us to achieve up to 85W of power at 1064nm with a linewidth less than 100 MHz. Furthermore, such SLM powers can be realized at rep rates up to 10 kHz enabling a myriad of next generation of narrow linewidth laser applications. We have built both water-cooled and air-cooled versions of theses SLM lasers for various power level requirements.

7684-50, Session 12

New remote sensing concepts to advance future mission capabilities

W. Cottingame, S. P. Palese, B. K. Baldauf, C. Bracikowski, M. M. Valley, Northrop Grumman Aerospace Systems (United States)

Multi-beam ladar sensor for ranging to collect data on the topography of ice sheets and the thickness characteristics of sea ice would improve mission performance and deliver more science value.

7684-51, Session 12

Special modulated beams for cylindrical coordinates in anisotropic media using computer algebra

S. Echeverri, Univ. EAFIT (Colombia)

An extension of the solution for the propagation of modulated beams through homogeneous media in cylindrical coordinates which results in a wave function described by Bessel Beams is the basis for this analysis of modulated beams through non homogeneous media in cylindrical coordinates. By solving the wave equation analytically, including functions that describe the non-homogeneity, and using computer algebra software such as MAPLE©, we formulate new kinds of beams defined by special functions such as Airy, Kummer, Hypergeometric and Heun functions. We also present convergence issues around the axis of propagation and possible applications for these new beams in telecommunication systems.

7684-52, Session 12

MEMS-scanned LADAR sensor for small ground robots

B. L. Stann, J. F. Dammann, M. M. Giza, U.S. Army Research Lab. (United States); P. Jian, Aerotek Inc. (United States); W. B. Lawler, U.S. Army Research Lab. (United States)

The Army Research Lab (ARL) continues research to build a short-range ladar imager for small unmanned ground vehicles (UGV) for navigation, obstacle/collision avoidance, and target detection and identification. The desired performance goals include a 6 Hz image update rate, an image size of 256 (h) x 128 (v) pixels, a 60º x 30º field of regard, 20 m range, eyesafe operation, and 40 cm range resolution (with provisions for super-resolution or accuracy). The ladar will be integrated on an iRobot PackBot. The ladar design is based on a newly developed but commercial MEMS mirror and a miniature and low-cost pulsed Erbium fiber laser. Last year, we reported on our unique design concept that will allow the final version of the ladar to meet the performance, cost, and size requirements for small UGV applications. We also showed imagery collected in the lab of good quality and with sufficient signal-to noise (S/N) that imaging to 20 m in range is possible. This year we will highlight new progress on the ladar development and its improved performance. We will discuss how the S/N of the receiver was increased which allowed the integration of a lower power and low-cost fiber laser into the system. We also built a compact mirror driver circuit and completed the signal acquisition code so that accurate estimates of image pixel ranges were obtained leading to better image quality. Movies we collected with the ladar on a platform moving through a cluttered scene possess good quality. We plan to support integration of the ladar on to a PackBot during the last quarter of the fiscal year.

7684-53, Session 13

Improving quality of laser scanning data acquisition through calibrated amplitude and pulse deviation measurement

M. Pfennigbauer, A. Ullrich, RIEGL Laser Measurement Systems GmbH (Austria)

Newest developments in laser scanner technologies put surveyors in the position to comply with the ever increasing demand of high-speed, high accuracy, and high reliable data acquisition from terrestrial, mobile, and airborne platforms. State-of-the art-online waveform processing not only saves users from time-consuming post-processing to obtain true 3D point clouds, it also adds the assets of calibrated amplitude and reflectance measurement for data classification and pulse deviation determination for effective and reliable data validation. We present results from data acquisition campaigns in different complex situations. We also demonstrate the capabilities of online waveform processing for airborne laser scanning object classification and vegetation elimination.

7684-54, Session 13

Linear mode InGaAs avalanche photodiode arrays for LADAR imaging

G. M. Williams, Jr., Voxtel, Inc. (United States)

We report recent advances in the design and manufacture of monolithic low-noise InGaAs avalanche photodiode (APD) arrays. An etched mesa detector structure has been developed for near infrared (NIR) passive imaging and active tracking in the spectral band from 950 - 1650 nm. The detector array uses InGaAs APD pixels engineered for low multiplication noise and high avalanche gain, and incorporates a microlens array etched directly in the semiconductor substrate. Wafer-scale photolithographic integration of microlenses during wafer fabrication simplifies registration of lenses to detector pixels and avoids the cost and complexity of aligning and hybridizing separate microlens dice to detector array dice.

7684-55, Session 13

Fusing waveform LiDAR and hyperspectral data for species-level structural assessment in savanna ecosystems

D. Sarrazin, J. van Aardt, D. W. Messinger, Rochester Institute of Technology (United States); G. P. Asner, Stanford Univ. (United States)

The study of ecosystem structure, function, and composition has become increasingly important in order to gain a better understanding of how impacts brought by natural disturbances, climate, and human activity can alter ecosystem services provided to a population. Research groups at Rochester Institute of Technology and Carnegie Institution for Science are focusing on characterization of savanna ecosystems and are using data from the Carnegie Airborne Observatory (CAO), which integrates advanced imaging spectroscopy and waveform light detection and ranging (wLiDAR) data. This component of the larger ecosystem project has as a goal the fusion of imaging spectroscopy and wLiDAR data in order to improve per-species structural parameter estimation. wLiDAR has proven useful for extracting high vertical resolution structural parameters, while imaging spectroscopy is a well-established tool for species classification and biochemistry assessment. We hypothesize that the two modalities provide complementary information that could improve per-species structural assessment and species classification when compared to single modality sensing systems. We are exploring various approaches to data fusion at the pixel-, feature-, and decision levels, all of which hinge on our ability to reduce structural and spectral data dimensionality to those data features best suited to assessing

these complex systems. One of these approaches is based on principal component analysis (PCA) of both the spectral and the range data, which could help finding correlated features, and in turn improve classifiers. Results will be presented at the conference.

7684-56, Session 13

An improvement on accuracy of laser radar using a Geiger-mode avalanche photodiode by time-of-flight analysis with Poisson statistics

M. S. Oh, H. J. Kong, Korea Advanced Institute of Science and Technology (Korea, Republic of)

A new technique to improve the accuracy of direct detection time-of-flight (TOF) laser radar using a Geiger mode avalanche photodiode (APD) by reducing range walk error is presented. The range walk error refers to the change of the measured distance as a function of the waveform and energy of the laser-return pulse reflected from the target. The technique is based on the theoretical model, established with Poisson statistics, of the system and it enable to overcome the inherent limitation of Geiger mode APD so that the number of photons of the laser-return pulse is expectable within the range in which the target detection probability varies. The theoretical model for the detection probability of each time bin in a TOF histogram is derived after it is experimentally proved that the creation of primary electrons in the Geiger mode APD is Poisson-distributed. It is shown that the range walk error depends on the energy of the laser-return pulse at the Geiger mode APD with the theoretical model regarded as the TOF histogram of multiple laser pulses in a single-hit case. The method which reduces the range walk error with the center of mass detection in the TOF histogram is then proposed, and the experiment for its proof is carried out. The experimental results show that the theoretical model is appropriate and the range walk error is reducible within the range in which the detection probability varies.

7684-64, Session 13

Extended-range digital holographic imaging

N. L. Seldomridge, J. C. Marron, Lockheed Martin Coherent Technologies (United States); R. L. Kendrick, Lockheed Martin Advanced Technology Ctr. (United States); T. D. Grow, S. T. Thurman, C. W. Embry, A. T. Bratcher, Lockheed Martin Coherent Technologies (United States)

We report the results of experiments demonstrating large-format coherent imaging at a range of 1.5 km. For this work, we use digital holographic detection to record coherent data and are thus able to measure the complex-valued field from a flood-illuminated scene over an extended aperture. Images are formed using digital Fourier processing. The return light is interfered with a coherent reference beam, and the intensity of the interference pattern is recorded using a conventional large-format detector array. Experimental results obtained using a coherent, pulsed laser source operating at 1.6 microns are presented. We also demonstrate the utility of this technique for advanced imaging functions such as 3D imaging.

Conference 7685: Atmospheric Propagation VII

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7685-01, Session 1

Weak and strong off-axis beam scintillations and beam wander for propagation in turbulence

M. I. Charnotskii, Zel Technologies, LLC (United States)

We extend the theory of the on-axis beam scintillations (M. Charnotskii, Waves in Random Media, 1994) for the off-axis case beam points for weak and strong scintillation conditions. Theory is based on the parabolic equation for the beam wave propagation and Markov approximation for the calculation of the statistical moments of the beam intensity. We associate the beam wander with an instantaneous centroid displacement. For the general case of the arbitrary focused partially coherent Gaussian beam we examine the contribution of the beam wander to the average beam spread, and formulate the conditions for the optimal partially coherent beam focusing at the end of the turbulent propagation path. We use the Feynman path integral technique and asymptotic analysis to analyze the contribution of the beam wander to the on-axis and off-axis scintillations. Both strong and weak scintillation cases are considered. Beam scintillation index naturally separates in the uniform (axial) and inhomogeneous (radial) components that can be examined separately. Axial component carries most of the diffractive scattering effects whereas the radial component is mostly related to the pure geometrical perturbation. We show that similar to the on-axis beam scintillations the double scattering which is represented by the second order terms of the asymptotic expansions can be the dominant contributor to both weak and strong scintillation. Our results will be compared to the recent less rigorous treatments by Baker (JOSA-A, 2006) and Andrews et al (Opt. Eng., 2006).

7685-02, Session 1

Propagation of higher-order annular Laguerre-Gauss beams in atmospheric turbulence

F. E. Strömqvist-Vetelino, R. J. Morgan, Aerospace Missions Corp. (United States)

The extended Huygens-Fresnel integral, with a quadratic structure function approximation, was used to derive closed form analytical expressions for the mean irradiance and spot size of higher-order annular Laguerre-Gaussian beams propagating in atmospheric turbulence. Comparisons were made to free space propagation of Laguerre-Gaussian modes, in which the spatial distribution is preserved as the beam spreads due to natural diffraction.

7685-03, Session 1

A reanalysis of short-exposure turbulent effects on passive imaging

D. H. Tofsted, U.S. Army Research Lab. (United States)

In 1966, D. L. Fried developed a theoretical framework for describing the modulation transfer function of optical turbulence effects for short-exposure imaging, thereby extending Hufnagel and Stanley's model for long-exposure imaging. However, Fried's analysis was incomplete due to the dropping of a term related to phase-tilt correlation. He argued that this term carried a minimal impact, particularly under weak turbulence conditions. However, he then applied the analysis results under more general turbulence conditions. In this analysis, Fried's results are reexamined by reintroducing this dropped term. The analysis is then extended to show that the tilt-correction term is indeed small at low

turbulence levels, as Fried predicted. However, as turbulence levels increase, the new theory shows a degradation that occurs just as the coherence diameter falls below the aperture diameter scale. As a result, there is a distinctly lower correction due to angle-of-arrival effects at high turbulence levels. This theory also supports the concept of enhanced high spatial frequency recovery at low turbulence levels.

7685-04, Session 1

Near-surface anisotropic turbulence

C. L. Klipp, U.S. Army Research Lab. (United States)

Current theories of atmospheric turbulence focus on isotropic turbulence which applies only to the smaller spatial scale/higher frequency temporal scale motions. The larger spatial scale/lower frequency eddies carry more energy and are more active in the transport of surface properties such as heat and water vapor. These larger eddies are anisotropic - the variances at these scales are not the same in all directions.

The variations in heat and water vapor carried by these large, anisotropic eddies may play a critical role in the nature and degree of atmospheric distortion. These temperature and humidity variations may affect systems other than electro-optical, such as terahertz band and radar propagation, where humidity effects are stronger. Anisotropy may also explain certain propagation anomalies such as angle-of-arrival and beam wander effects that are not axis-symmetric. A better understanding of the statistical properties of the anisotropy may lead to better prediction of the conditions which lead to different degrees of distortion as well as to better strategies for mitigation of distortion.

This presentation will look at the degree and nature of anisotropy at a variety of elevations from the surface up to 50m, focusing on the lowest 10m, at several flat and open locations: CASES99 near Leon, Kansas, JU2003 in Oklahoma City, Oklahoma and 3DTS at White Sands Missile Range, New Mexico.

7685-05, Session 1

Computer algebra for the calculation of the Tutte and chromatic polynomials in applications to the atmospheric telecommunication

N. N. Ramirez, Univ. EAFIT (Colombia)

The present work is a study of the relationship between the different devices of the atmospheric telecommunication as plains, narrowband, gateway and others. Through one algebraic analysis of the graphic corresponding than describes them relationships. This algebraic analysis, is put through of the Tutte polynomial, as well as a second analysis additional whit the Chromatic polynomial, for analyze one possible way to organized the different bands of channels communication of such devices.

Present work is about a study of the relationship between the different devices as satellites of telecommunication, plains, narrowband gateway, etc, presents in the atmosphere through one analysis whit the Tutte polynomial than allows view algebraically this relationship.

7685-06, Session 2

Optical communications receiver arrays

J. M. Saint Clair, E. Y. Chan, D. G. Koshinz, S. K. Wilcken, The Boeing Co. (United States); D. C. Soreide, Optimal Aerospace LLC (United States); A. Joshi, H. Durmus, Teledyne Imaging Sensors (United States)

One of the major challenges to free space laser communications and laser radar is the impact of turbulence on beam propagation, one example of which is signal fading. These impacts can be exacerbated on airborne platforms by turbulence in the vicinity of the laser system aperture and the platform wake. There are a number of strategies to mitigate this, including adaptive optics, active flow control, and various dimensions of diversity: wavelength, polarization, temporal, and spatial diversity. In this paper we will discuss spatial diversity implemented in the focal region of optical telescopes. We will briefly compare this with other methods, describe results of requirements analysis of array features and optical configurations for various atmospheric turbulence states, and suggest several attractive configurations. We will also report on the design and test of one configuration, implemented in a prototype, and tested for noise performance, optical transmission, modulation bandwidth, and BER performance with our dynamic turbulence simulator. Early evidence shows significant BER improvements of several orders of magnitude at high turbulence fluctuation frequencies using this technique.

7685-07, Session 2

Avalanche photodetector development at NRL

L. M. Wasiczko Thomas, H. R. Burris, Jr., W. S. Rabinovich, U.S. Naval Research Lab. (United States)

This paper will describe NRL's new research program in 1550nm Avalanche Photodetectors.

7685-08, Session 2

Acoustic mitigation of atmospheric disturbances for improved beam propagation

A. Z. Ullman, S. F. Griffin, D. A. Nahrstedt, The Boeing Co. (United States)

Operation of airborne laser weapons or laser communicators produce disturbances to the surrounding atmosphere that disturb the propagation of the laser beam either from the laser system hardware (e.g., turret) or the aircraft (e.g., rotor blades, aircraft body). These disturbances degrade propagation and need to be corrected to produce high system capability. Options such as beacons and deformable mirrors can ameliorate these effects, but are complex and costly. The use of acoustic drivers to create a counterbalancing density field is proposed, since these can be inexpensive, simple and robust. Quantification of the flow disturbances can be non-optical, including flow and acoustic sensors. Performance of a rotorcraft and turret disturbance cancellation systems are discussed.

7685-09, Session 2

Prediction of the ground-level refractive index structure coefficient from the measurement of atmospheric conditions

T. Leclerc, Univ. of Central Florida (United States)

An evaluation of the method, developed by Norman S. Kopeika [Ref: A System Engineering Approach to Imaging, pp 462-464, SPIE 1998] to predict the refractive index structure coefficient from the direct measurement of atmospheric conditions. Measurements of ground-level temperature, relative humidity, wind speed, solar flux, and aerosol loading taken by the University of Central Florida (UCF) weather station will be compared against concurrent measurements of the refractive index structure coefficient made by multiple scintillometers positioned near the weather station. Scintillometer systems include: two Scintec SLS-20 Scintillometer, one Scintec BLS-900 Scintillometer, and one UCF 3-Aperture Scintillometer. Wind measurements were obtained by

three, three-axis sonic anemometers (capable of measuring the three-dimensional wind vector) positioned at 1, 1.5, and 2.5 meters above the ground. Temperature measurements were taken at ground level, and at heights of 1 and 1.5 meters. Data was collected for several days in a humid, vegetative environment (Kennedy Space Center, FL) and then for several more days in a dry, desert environment (Antelope Peak, NV). Collection times varied, but generally contain both day and night measurements.

7685-10, Session 2

Experimental evaluation of a misalignment tolerant FSO receiver

S. Pondelik, P. G. LoPresti, The Univ. of Tulsa (United States); H. Refai, M. Atiquzzaman, Univ. of Oklahoma (United States)

In order to track, acquire and maintain a free-space optical link between mobile platforms experiencing misalignment due to movement and atmospheric turbulence requires a different approach than traditional free-space optical transceivers. Recent investigations of alternative receiver configurations found that a lens array performed better than a collimator array as a light collector, and compared methods for summing light collected from different lenses in the array. This paper reports on experimental investigations of receiver performance for two different lens arrays and an aspheric-lens based summing approach. The receiver performance is evaluated using two different transmission systems, including a SONET bit-error-rate tester. Key evaluation parameters include the received power, eye diagrams, and achieved bit-error rate. Measurements are made under perfect alignment and under a variety of misalignment conditions. The investigation finds that size of the lenses used in the array, which dictates the number of collecting fibers used, impacts the effectiveness of the summing approach. A slightly larger lens size produces a better result for the majority of evaluation parameters and conditions. Optimization of the summing optics is required for the receiver to be effective for high data rate communication.

7685-27, Poster Session

Analysis of the characteristics of atmospheric turbulence in marine surface of South China Sea based on the routine meteorology factors

D. Chen, Naval Academy of Armament (China)

The method of estimation refractive index based on meteorology factors offered by Friehe et al is used to the district of South China Sea. The data consists of water temperature, air temperature at height z, water vapor density adjacent to the sea surface and average water vapor density at height z, the average wind speed is also included to estimate the atmospheric turbulence in typical marine surface layer.

The overall image of atmospheric turbulence is established by using the algorithm based on the mean field of the 33-year meteorology factors. Then we make a statistic on the temperature differences by month, and the variances of temperature differences of 12 groups in every observation point are obtained, we chose the maximum and minimum month in the variance of temperature differences to indicate the distribution of the statistics the strength of atmospheric turbulence in marine surface, the whole scenes of typical marine atmospheric turbulence are established. The results show that the range of mean turbulence intensity is from 1e-16 to 1e-13 m-2/3; the seasonal variation range of atmospheric turbulence intensity on marine surface in South China Sea is not obvious. In general, turbulence intensity is a little bit stronger in winter than in summer. And the sea-coastal turbulence intensity is stronger than that of mare liberum. It may be related to the effect of land frontier to wind speed and the effect of land thermal radiation. A statistical method for analysis of complex spatial and temporal distribution characteristic value is presented meanwhile.

7685-11, Session 3

Visualizing aero-optic interactions about a nose-mounted turret

J. M. Cicchiello, Northrop Grumman Electronic Systems (United States); S. R. Harris, Flatiron Research (United States); C. A. Prudden, J. Neiswender, Air Force Research Lab. (United States); D. W. Bope, C. J. Harkrider, T. G. Moore, Northrop Grumman Electronic Systems (United States); B. K. Stadler, Air Force Research Lab. (United States); L. B. Stotts, Defense Advanced Research Projects Agency (United States)

One aspect of the propagation-physics challenge associated with airborne, free-space, optical communications (FSOC), for example, is the characterization and mitigation of link losses due to aero-optic interactions. That is, air-density gradients due to compressibility effects in turbulent boundary layers, separated flows, and free-shear flows can disturb the wavefront in the near field of the transceiver. To better understand these aero-optical mechanisms, a model of a nose-mounted, FSOC transceiver recently was placed in a compressible-flow wind tunnel, and the resulting wavefront degradations, as a function of flow scenario, were recorded. High-speed, time-resolved movies of the aero-optic disturbances have been realized, using a Schlieren-imaging technique, and a very-high-frame-rate camera. Discrete, vortical structures (amid otherwise-irregular shedding) were seen to emerge and convect past the clear aperture. The frequencies of these disturbances have been estimated from the movies, and these have been compared with high-speed, time-resolved wavefront reconstructions. The system-level impact of the resulting wavefront degradations will be discussed.

7685-12, Session 3

ATL turret aerodynamic effects

A. Z. Ullman, D. A. Nahrstedt, S. F. Griffin, Y. Hsia, The Boeing Co. (United States); S. Gordeyev, E. J. Jumper, Univ. of Notre Dame (United States); D. Saunders, M. Stanek, C. McGaha, Air Force Research Lab. (United States)

The design and operating experience of the Advanced Tactical Laser (ATL) turret is reviewed, identifying test results that pointed to unanticipated flow instabilities. These instabilities were found to impact the jitter due to fluctuating loads on the turret and optics. CFD analyses and wind tunnel tests were performed to verify this association. These results will be reviewed, and design guidelines will be described that minimize aerodynamic impacts on laser weapon performance. Design and analysis guidelines for airborne laser weapons, laser communications and other systems are proposed.

7685-13, Session 3

Field and laboratory validation of surface layer optical turbulence and off-axis irradiance

S. T. Fiorino, J. D. Haiducek, C. A. Rice, M. J. Krizo, R. J. Bartell, S. J. Cusumano, Air Force Institute of Technology (United States)

The effects of optical turbulence on high energy laser propagation have been well documented. The optical turbulence is typically characterized using the index of refraction structure parameter, Cn2. The value and 3-D variation of Cn2 can be accurately diagnosed for the surface boundary layer (lowest 50 m of the atmosphere) from values of temperature, pressure, humidity and wind velocity using meteorological similarity theory. Examples of such similarity theory Cn2 calculators include the Tunick model for overland applications and the Navy Surface Layer Optical Turbulence (NSLOT) model for ocean scenarios, both of which are implemented in the AFIT CDE's (Center for Directed Energy)

HELEEOS (High Energy Laser End-to-End Operational Simulation) and LEEDR (Laser Environmental Effects Definition and Reference) models where they can be assessed from 400 nm to 8.6 m, continuously. The HELEEOS model further allows for the calculation of the irradiance from within a HEL beam that is scattered by molecules and particulates in the atmosphere to an off-axis observation point, while incorporating the spreading effects of the turbulence and thermal blooming.

Field and laboratory experiments conducted at Wright-Patterson AFB, Ohio in summer 2009 allowed for validation measurements for the surface layer optical turbulence and off-axis algorithms to be collected. Turbulence strength measurements were made at a wavelength of 1.55 μm using a state of the art bistatic turbulence profiler for both horizontal and vertical paths. Pressure, wind speed, wind direction, relative humidity and aerosol loading data were collected simultaneously with the Cn2 measurements. As part of the experiment, the profiler's beams were imaged off-axis with a calibrated camera array and the received irradiance of the off-axis scattering was quantified. Characterization of the aerosol distribution along the laser path and the path to the observer is accomplished by determining the visibility and climatological aerosols for southwestern Ohio. Comparisons between predicted and measured Cn2 and off-axis irradiance are made.

7685-14, Session 3

Passive flow control around turrets for improved field of regard (FOR)

A. Z. Ullman, D. A. Nahrstedt, D. T. Yeh, The Boeing Co. (United States); S. Gordeyev, E. J. Jumper, Univ. of Notre Dame (United States)

Use of airborne laser weapons with turrets mounted beneath the aircraft is limited to projecting towards the forward quadrant due to flow instability and turbulence that is create after of the turret as the flow separates from the turret body. The use of Boeing's Tip Vortex Flow Control (TVFC) technology allows this effect to be largely eliminated. In this approach, counter-rotating vortexes are generated aft of the turret by placing a split "collar" around the turret adjacent to the aircraft body. The vortexes reduce the local pressure on the aft side of the turret and eliminate the flow separation. Analyses and wind tunnel test results are presented that show the impact on the TVFC flow collar on flow stability and beam propagation efficiency. Other applications of this technology to laser weapons are described.

7685-15, Session 3

Frequency characteristics of atmospheric turbulence in space-to-ground laser links

M. Toyoshima, H. Takenaka, Y. Shoji, Y. Takayama, National Institute of Information and Communications Technology (Japan)

Laser communications experiments between an optical ground station and a low earth orbit (LEO) satellite were successfully conducted from 2006 to 2009. The optical ground station is located in Koganei, Tokyo, which was developed by National Institute of Information and Communications Technology (NICT), Japan. Four laser beams were transmitted from the optical ground station to the LEO satellite in order to reduce the intensity fluctuation of the optical signal due to atmospheric turbulence. The frequency chracteristics of the downlink is evaluated based on the theory and the measurement that was sampled at 20 kHz. The speckle patterns are averaged and the frequency response of the received optical signal is filtered by the telescope aperture. The basic idea in terms of the frequency characteristics is derived and compared with the measured results.

7685-16, Session 4

Free-space optical channel characterization in the maritime environment

J. C. Juarez, J. E. Sluz, C. Nelson, M. B. Airola, D. W. Young, D. H. Terry, F. M. Davidson, R. M. Sova, The Johns Hopkins Univ. (United States)

The performance of a free-space optical (FSO) communications link at 2.5 Gbps in a maritime environment was evaluated during two field trials conducted off the mid-Atlantic coast near Wallops Island, VA, in July and September 2009. Bi-directional, ship-to-shore data links operating at 2.5 Gbps and utilizing commercial, single-mode adaptive optics terminals were set up between a lookout tower located on Cedar Island, VA and a JHU/APL research vessel over runs ranging from 2-17 km (optical horizon).

The FSO link was instrumented to characterize the impact of optical turbulence on the spatial and temporal properties of the laser beam along the propagation path. This was achieved with an IR camera imaging the beam profile and independent apertures measuring power-in-the-bucket at the receiver plane, respectively. Local seeing conditions were also characterized with a scintillometer recording Cn2 at the tower location with a measurement path parallel to the link path. Additionally, environmental data such as temperature, relative humidity, and wind speed were recorded on the research vessel.

This paper will present the test configuration, discuss the overall performance of the FSO channel, and compare it to the available turbulence and weather measurements. Additionally, modeling of the link configuration will be presented and comparisons will be made to data measured throughout the experiment such as received power, received beam diameter, and local Cn2.

7685-17, Session 4

The ONR enabling capability on high-bandwidth Lasercomm

L. M. Wasiczko Thomas, C. I. Moore, W. S. Rabinovich, U.S. Naval Research Lab. (United States)

This paper will discuss the new ONR Enabling Capability on High Bandwidth Free Space Lasercomm.

7685-18, Session 4

Long range audio laser communication link in a maritime environment

K. J. Grant, Defence Science and Technology Organisation (Australia); H. R. Burris, Jr., C. I. Moore, U.S. Naval Research Lab. (United States); W. Martinsen, J. E. Giesbrecht, B. A. Clare, T. Nottage, K. A. Mudge, Defence Science and Technology Organisation (Australia); G. C. Gilbreath, W. S. Rabinovich, U.S. Naval Research Lab. (United States)

The Defence Science & Technology Organisation (DSTO), in collaboration with the US Naval Research Laboratory (NRL), has performed long distance communications experiments on analogue modulated free space optical links across Chesapeake Bay, Maryland. In this work, pulse frequency modulation (PFM) of a laser pulse train was used to transmit audio signals over a 32km folded path.

A dual-mode optical interrogator was used to launch the optical signal (pulse width 5ns, wavelength 1547nm, and mean power +34dB) and receive the signal returned from a 25-element 2" diameter retro-reflector array 16 km distant on the far side of the Bay. The received optical power was coupled to a pinfet photodiode with automatic gain control to help mitigate the effect of atmospheric scintillation noise.

The system was used in a series of PFM music transmissions. Subjectively the quality of the audio was very good, with little discernible hiss. There were only very occasional 'pops', presumably due to momentary loss of signal due to deep fades. By transmitting a 10 kHz tone with a modulation index of 0.1, the carrier-to-signal ratio was estimated to be 25.2 dB, which is comparable to the theoretical value of 26.0 dB.

In addition, still images were transmitted using the Scotty 1 protocol of slow scan television. A limitation of this technique is that the transmission time is 110 s. Techniques are under development to decrease transmission time to a few seconds, by making more efficient use of the available bandwidth.

7685-19, Session 4

Effects of beam wander on free-space optical communications through turbulent atmosphere

Z. Zhao, R. Liao, Michigan Technological Univ. (United States)

Propagating through the turbulent atmosphere, the laser beam of a free-space optical (FSO) communication system experiences random wave front distortion, beam broadening, and beam wander. These result in the received optical signal power fluctuation (called fading) and average received power loss at the receiver of a FSO communication system with focused or collimated laser beam and finite receiver aperture size. Compared with a FSO communication system with fast-tracked laser beams, an untracked system experiences both deeper fading and long-term beam broadening due to beam wander, and therefore it suffers more severe system bit error rate (BER) performance and reliability degradation. This paper studies the effects of beam wander on the uncoded BER performance of direct detection FSO communication systems using focused and collimated laser beams. Using the multiple random phase screen method and the Kolmogorov turbulence model, the fading statistics of both untracked and fast-tracked horizontal laser beams are obtained using large-scale computer simulations for a wide range of turbulence strengths, different propagation distances, and various receiver aperture sizes, and they are compared with different closed-form theoretical models. In the receiver, the avalanche photodiode (APD) is chosen for photo detection, and the accurate Conradi-McIntyre APD model is adopted for system performance evaluation. Results show that large performance gain (more than 10dB) can be achieved when the beam wander is perfectly tracked. Optimal receiver aperture sizes are also determined and discussed.

7685-20, Session 5

Near the ground laser communication system for monitoring the statistics of turbulence: anisoplanetic studies based on the PSF measurements

M. Roggemann, A. V. Sergeyev, C. Demars, Michigan Technological Univ. (United States)

The effects of the atmospheric turbulence on the laser beam which are relevant to optical communications are a broadening of the laser footprint, random jitter of the laser beam, and high spatial frequency intensity fluctuations referred to as scintillation. The developed multiphase approach is directed to statistically describe atmospheric turbulence using results derived from the experimentally collected data. To model the performance of a real system operating in the real world we have developed an outdoor 3.2 km, partially over water, turbulence measurement and monitoring communication link. The communication system described in this paper has two transmitters and a receiver. The transmitter side is equipped with the laser and the bank of 14 horizontally, in-line mounted LEDs. The receiver side consists of two channels. The channel I (WFS) captures the signal from the laser

transmitter and specifically designated for the wavefront sensing. The WFS channel consists of the relay optics, a Hartmann WFS, and a CCD camera. The channel II (PSF) is designed to capture the signal from LED bar and consist of the relay optics and CCD camera. The data collected from the WFS channel is used to estimate Fried parameter r_0 from the WFS measurements. In this paper we emphasize out attention on the data collection and studies of anisoplanetic effects from the data collected via PSF channel only. The results presented in this paper are based on the 6Tb of data collected through 50 days time interval, and under various day and night atmospheric conditions.

7685-21, Session 5

Effects of thermal blooming on systems comprised of tiled subapertures

M. F. Spencer, S. T. Fiorino, S. J. Cusumano, C. L. Leakeas, J. J. McCue, M. J. Krizo, R. J. Bartell, Air Force Institute of Technology (United States)

Solid state slab and fiber laser technologies are rapidly emerging in the directed energy community. The Air Force Institute of Technology's Center for Directed Energy's (AFIT/CDE), under sponsorship of the HEL Joint Technology Office, previously developed the first scaling-law performance models of laser weapon system configurations consisting of tiled arrays of both slab and fiber subapertures and which account for optical turbulence along the path. These performance models are based on results of detailed waveoptics analyses conducted using WaveTrain. This initial performance model is now part of the Scaling for High Energy Laser and Relay Engagement (SHaRE) toolbox. Thermal blooming effects, caused by heating of the air along the beam path, can have a major impact on high energy laser propagation through the atmosphere. In this work the tiled subaperture performance models are extended to correctly account for the effects of thermal blooming on the performance of such generally weakly focused systems. In addition use of an adaptive optics system to mitigate phase distortions due to thermal blooming is investigated. Preliminary results indicate this problem can be investigated with WaveTrain or a straightforward in-house wave optics code.

7685-22, Session 5

Complete affordable system for long path simultaneous VIS/NIR and MWIR/LWIR spectral atmospheric transmittance measurements (ATMS)

D. Cabib, A. Gil, O. Biran, CI Systems (Israel) Ltd. (Israel)

During the second half of the '70's Ben-Shalom et al. developed a system for research of the spectral transmittance (SAT) of the atmosphere in the infrared range (Infrared Physics, Vol. 20, pp. 165-174 (1980)) on nearly horizontal sea level atmospheric paths between 2.5 and 14 microns. On clear days the longest path shown was of 44 Km., which was an achievement that to our knowledge has not been surpassed since. However, the system required a very high temperature (2400K) short lived (3 hours) emitter element, home-built projection optics, and a cumbersome closed cycle water cooling system for the source. The sensor end of the system was a Circular Variable Filter (CVF) based spectroradiometer with interchangeable liquid nitrogen (LN2) cooled detectors. The signal processing electronics was based on a synchronous detection method making use of a chopper at the source and of a radio-transmitted reference signal.

In this paper we describe the Atmospheric Transmittance Measurement System (ATMS) we recently built and tested. Its main advantages over the above are: it is built of only commercial off-the-shelf items (COTS), it can measure in both the IR and visible ranges simultaneously, it is cost effective and easy to maintain. A standard 1473 K blackbody cavity of practically unlimited life for the IR range, a 100 hour life time halogen lamp for the VIS/NIR range, a single telescope widely used

by astronomers for radiation projection in all spectral ranges and an off-the-shelf radio transmitter/receiver for the chopper reference signal are used. The spectroradiometer is a standard CI product (SR 5000). The calibration method and algorithm, insuring good accuracy, are also described. A nearly horizontal sea level path of 6.5 Km. has been shown for the whole spectral range of 0.4 to 14 microns in less than ideal weather conditions and without any particular effort to signal average over long measurement times. For these reasons we believe that the ATMS can be used for much longer paths, although the limits have not been investigated. In addition and in contrast to the old '70's system, which could be used only for measurements above 1 Km. paths, the ATMS is built and calibrated so that it can measure transmittance in extremely foggy conditions through paths of few tens of meters: this feature may be useful to develop aircraft take-off and landing aids.

7685-23, Session 5

Three-dimensional near-surface turbulent anisotropic structure function measurements

D. H. Tofsted, U.S. Army Research Lab. (United States)

A common assumption used in describing the turbulence structure present during atmospheric propagation is isotropy. Yet low frequency fluctuations obviously cannot exhibit the same spectral properties as horizontal fluctuations due to the hard boundary presented at the surface. Strong vertical gradients also appear in the strength of turbulence near the surface. To gain insight into the nature of these anisotropic influences, a measurement campaign was carried out in the spring of 2008 at White Sands Missile Range, NM. A 2D array of 3D sonic anemometers arranged in a 14m (wide) by 10m (high) grid was used to sample wind and temperature fluctuations over a two-month period. Overall, some 300 hours of data were collected that fit the criteria of sensor availability and mean winds directed from a desired sector. This paper will describe the grid, the overall experiment, and consider aspects of correlations present in the temperature data fields useful for characterizing an anisotropic refractive index structure function. Such studies may be useful in describing anomalous angle-of-arrival effects and lead to combined two-dimensional and three-dimensional influences on atmospheric propagation.

7685-24, Session 6

Evaluation of a control algorithm for mobile FSO node alignment

D. Zhou, P. G. LoPresti, N. Ye, The Univ. of Tulsa (United States); H. Refai, M. Atiquzzaman, Univ. of Oklahoma (United States)

In order to track, acquire and maintain a free-space optical link between mobile platforms experiencing misalignment due to movement and atmospheric turbulence requires an efficient transmitter control system for pointing, acquisition, and tracking. Recently, a control algorithm was proposed that incorporated a fiber-bundle approach for beam steering at the transmitter in addition to GPS data exchange, alignment systems, and unique properties of the receiver. This paper investigates the performance of the proposed algorithm through both simulation and experimental methods. The performance is evaluated on several key parameters, including the acquisition time, required control system bandwidth, and the connection up-time during tracking. The dependence of the key parameters is evaluated as a function of important transmitter design choices, including transmitted power, switching time between fibers in the bundle, and coverage area at the receiver plane. Receiver parameters are fixed to focus the study on the transmitter. The effects of turbulence are also considered. Simulations find that the rate at which target GPS data is refreshed and the coverage area of the transmitter greatly impact the effectiveness of the control algorithm, with higher refresh rates and larger coverage areas reducing acquisition times, increasing link up-time, and relaxing the requirements on the system bandwidth. Experimental implementation of the algorithm confirms the simulation results.

7685-25, Session 6

Coherence of beam arrays propagating in the turbulent atmosphere

M. I. Charnotskii, Zel Technologies, LLC (United States)

We analyze some recent publications addressing propagation of the partially coherent polarized beams and beam arrays in the turbulent atmosphere. We show that the published results are limited to the scalar propagation model, and are not particular to the beam polarization. Therefore these results are equally relevant for the scalar beam pairs and arrays discriminated by some parameters such as small frequency shift, time delay or geometry, but not necessary the polarization. We use the virtual incoherent source model to derive the general form of the mutual coherence function of the two Schell-type beams. We discuss some physical stochastic models that result in the creation of the Schell-type beams and beam arrays. New classes of the uniformly, nonuniformly and nonlocally coherent beam pairs emerge naturally from this analysis.

We use a rigorous Markov approximation-based propagation model to describe propagation of the partially-coherent individual beams and beam pairs. For the second-order moments of the optical field this theory provides relatively simple analytic results. We discuss the relation of the Markov approximation to some heuristic or perturbation-based propagation models used in the previous publications. We reveal some interesting features of the average beam intensity and proceed to derive the general expressions for the coherence matrix of the beam pair. We examine the changes of the beam mutual coherence in the process of the free-space propagation and propagation through the turbulent atmosphere. We find the conditions on the initial coherence that warrants preservation of the mutual coherence of the Schell-type beam pair propagating in the turbulent atmosphere. We will also discuss the alternative multi-mode model of the partially-coherent beams.

7685-26, Session 6

Model validation of turbulence effects on orbital angular momentum of single photons for optical communication

F. E. Strömqvist-Vetelino, R. J. Morgan, Aerospace Missions Corp. (United States)

The orbital angular momentum of photons in paraxial beams offers the possibility of arbitrary base-N digits for free-space laser communications. Atmospheric turbulence can cause the orbital angular momentum of photons in a propagating beam to scatter from its original azimuthal mode. The probability of obtaining correct or incorrect measurement of the transmitted orbital angular momentum state after propagation through atmospheric turbulence is calculated from the rotational field correlation (second order field moment). A previously published model of the rotational field correlation for Laguerre-Gaussian beams is limited to the weak turbulence regime and assumes that the turbulence effects can be considered a pure phase perturbation. This model is validated by calculating the same quantity with the extended Huygens-Fresnel integral, valid in all regimes of turbulence. To obtain closed form expressions, a quadratic structure function approximation was applied. The probability of receiving the transmitted orbital angular momentum state was calculated and compared to the existing model. The results indicate that the quadratic structure function approximation leads to a slight over prediction of the probability in the weak turbulence regime. For finite transmitter apertures, the previously published model, with a spherical wave structure function, rather than the plane wave structure function used in the original work, is believed to be the most accurate model in the weak turbulence regime.

7685-28, Session 6

The code MaexPro for calculation of aerosol extinction in the marine and coastal environment

G. A. Kaloshin, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

No abstract available

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7686-01, Session 1

Recent advances in the development of scheelite-like $MT_{1-x}Ln_x(WO_4)_2$ lasers

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MT(WO4)2 (M= monovalent and T= trivalent cations) single crystals with tetragonal scheelite-like structure have been recently reconsidered as hosts for Yb3+ (1050 nm), Tm3+ (1950 nm) and Ho3+ (2050 nm) lasants. Due to a local structural disorder, the bandwidths of the electronic transitions of trivalent lanthanides (Ln) are large. This spectral property allows the efficient absorption of diode laser emissions used for pumping around 800 nm and 980 nm. Moreover, it has been also used to support <100 fs mode-locked laser pulses at about 1050 nm and in continuous wave operation the broad laser tunability, 1850-2050 nm for single doped Tm3+ crystals, has been extended up to 2090 nm by codoping with Ho3+. The nature of the local structural disorder giving rise to the large bandwidths and the recent laser results obtained in isostructural crystals of this family are described. Single crystals of most of these compounds have been traditionally grown by the Czochralski method. New developments to prepare nano/micron-sized powders and films of these compounds by hydrothermal, sol-gel and liquid phase epitaxy methods are described.

7686-02, Session 1

Compact very lightweight Nd:YAG LADAR transmitter

J. C. McCarthy, K. J. Snell, C. L. Willis, R. C. Day, E. P. Chicklis, BAE Systems (United States)

We describe the performance of an innovative, low weight laser architecture which significantly reduces Laser Transmitter weight and power consumption - providing active sensing capability for advanced, extremely low weight ground and airborne platforms. Details of the advanced materials used and method for elimination of complex optical subassemblies and laser performance will be reviewed.

7686-03, Session 1

Q-Peak sources for advanced remote sensing

J. H. Flint, Q-Peak, Inc. (United States)

We will describe several laser systems recently developed at Q-Peak for defense remote sensing applications. One is a 250-kHz, 900-ps, 5-W green laser developed specifically for long-range LADAR applications. It is passively Q-switched using a saturable Bragg reflector developed at MIT. Another is a diode-pumped Yb:doped femtosecond regenerative amplifier laser system for LIBS. The system utilizes CPA approach with novel chirped volume Bragg grating technology. A third system has two rapidly-tuned OPO's that are each frequency doubled to cover the 210-300 nm wavelength range. We also have several coherent and incoherent lidar transmitters under development at 1, 1.5, and 2 µm.

7686-04, Session 1

1.4-W mode-locked ceramic Yb:YAG laser

M. Vannini, G. Toci, A. Pirri, D. Alderighi, Istituto di Fisica Applicata Nello Carrara (Italy)

Recent investigations on diode-pumped solid-state-lasers have focused on polycrystalline ceramic laser because, in comparison with single crystal samples, they are easier to fabricate and less expensive. Moreover, ceramic materials allow a more uniform distribution of dopants. One of the most promising methods to achieve high-power ultra-short laser system is the use of Yb-doped material. The main advantage of Yb3+ ion is the presence of only two manifolds which reduce quantum defects, determining relatively low thermal loads and avoiding up-conversion losses, excited states absorption effects, and cross relaxation. The strong coupling of the Yb3+ energy levels with the crystalline field, results in broad absorption and emission spectra and therefore in a wide range of tunability. In consequence it allows short pulse generation.

We present a relatively high power mode-locked Yb3+ (9.8% at.) doped YAG commercial ceramic. To the best of our knowledge our system is the most efficient mode-locked ceramic Yb:YAG as the first and only one result until now reported in literature showed 250mW of power vs. a pump power of 26.6W. Our laser in mode-locking regime exhibits an output power of 1.4W at 1050nm with a diode pump power of 9.2W in CW operation mode at 940nm. Measured pulsed duration is 4ps and cavity length is 1.25m. No special dispersion compensation device (GVD) is used; this is the reason of the relatively longer pulse duration. We employ to induce the mode-locking regime a SESAM in transmission. Its transmittance is 3% at 1040nm.

7686-05, Session 1

Diode-pumped cryogenic Yb_{3+}:YLF laser of 100-watt output power with high beam quality

L. Zapata, D. Miller, D. J. Ripin, T. Y. Fan, MIT Lincoln Lab. (United States)

On the path to an efficient femtosecond (fs) laser source for high-power applications we are developing a cryogenically cooled Yb3+:YLF laser. Early in our program, a simple 2-mirror power oscillator pumped by a 940-nm fiber-delivered diode array has demonstrated 96-watts average power at 1.0-µm wavelength with near-diffraction-limited output and 57% slope efficiency (relative to absorbed pump power). We will report on our progress including the incorporation of a 960-nm diode pump for optimized absorption, and the development of a master oscillator with fs-pulse format.

7686-06, Session 2

High-power fiber lasers for the shortwave infrared

S. D. Jackson, The Univ. of Sydney (Australia)

Silicate glass based fiber lasers emitting in the shortwave infrared spectrum, i.e., 1.4 microns to 3 microns are based on the phonon-terminated transitions of Er, Tm and Ho. In this review I will examine the pump, fiber and dopant configurations that have been tested in order to maximize the efficiency and output power produced from these transitions and I will highlight some of the issues that may need to be addressed in order to further scale the output power.

7686-07, Session 2

An eye-safe optical parametric oscillator system with more than 5-megawatts peak power

F. F. Wu, MetroLaser, Inc. (United States); J. W. Pierce, JP Innovations, LLC (United States)

We report an optical parametric oscillator (OPO) system operating at 1574 nm using KTP crystals, with output peak power of more than 5 megawatts, output pulse energy of up to 30 mJ per pulse, and pulse width of less than 6 nanoseconds at full width half maximum (FWHM). The OPO was pumped by a diode pumped Nd:YAG Q-switched laser, with pump energy of about 95 mJ and pulse width of approximately 7 ns. The conversion efficiency from 1064 nm Nd:YAG laser to OPO output at 1574 nm is more than 30%. The complete Nd:YAG / OPO system, compactly packed inside a case with foot print measuring 15" x 9" x 5.3", was tested over an operating temperature range of -20 C to +35 C and a storage temperature range of -40 C to +50 C without significant power or performance variations.

7686-09, Session 2

1645-nm Q-switched Er:YAG laser with in-band diode pumping

I. Kudryashov, A. Katsnelson, Princeton Lightwave, Inc. (United States)

Growing interest in high peak power lasers in the eye-safe spectral domain near 1.6 μm has spurred progress in the development of solid-state lasers (SSLs) based on Er3+-doped materials. With resonant pumping of the SSL, a significant portion of the thermal load is shifted from the gain medium to the pump diodes, providing significant reduction in gain medium thermal distortions. This reduction in thermal distortion opens the possibility for dramatic SSL power scaling while maintaining high beam quality. In this paper, we report results for a resonantly diode-pumped Q-switched Er:YAG laser exhibiting an output pulse energy of more than 11 mJ with pulse widths shorter than 50 ns. We utilized an end-pumping geometry with a 1470 nm laser diode pump source based on the combination of individual emitters. High spectral brightness was achieved for the pump diodes by implementing volume Bragg gratings to narrow the pump spectrum. A pump spectral width of less than 1 nm allowed for "in-line" pumping of Er3+. The beam quality of Q-switched Er:YAG SSL was characterized by M2 < 1.2.

7686-10, Session 2

A 400W cryogenic Er:YAG laser at 1645 nm

M. J. Shaw, S. D. Setzler, K. M. Dinndorf, M. J. Kukla, J. A. Beattie, E. P. Chicklis, BAE Systems (United States)

We report on the design and characterization of a cryogenically cooled, resonantly pumped Er:YAG slab laser operating at 1645nm. The Er:YAG slab is conductively cooled by liquid nitrogen and face-pumped by a 1.4kW diode array operating at 1452nm. The slab is transversely extracted in a multi-mode oscillator, producing 380W of cw output power and 392W of power at 50% duty cycle. We have measured >50% slope efficiency and approximately 40% optical conversion efficiency (relative to incident pump). We will describe the design of the cryostat, slab mount, and the pump diode array, as well as report on the oscillator design and performance, as well as present data on other, similarly configured, face-pumped cryogenic slab lasers.

7686-43, Session 2

Efficient lasers for remote sensing

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Lasers for remote sensing based on Nd:YAG and OPO- or Raman-technology for wavelength conversion are developed at Carl Zeiss Optronics for a variety of military applications.

For the BELA (Bepi Colombo Laser Altimeter) instrument on the BepiColombo mission of ESA a diode pumped Nd:YAG Laser will be used to enable accurate mapping of the mercury surface from a 400 to 1500 km orbit. The Laser design addresses the requirements for low power consumption, high reliability and long operational life for this space mission. This is combined with a close to diffraction limited beam quality, a pulse duration of less than 8 ns and a wide operating temperature range. We present details on the technological solutions applied to this Laser and preliminary results on measured Laser parameters.

The technology of this Laser is applied to a military dual wavelength Laser transmitter for target designation and ranging. This Laser uses Nd:YAG for the designation wavelength and OPO wavelength conversion for the eyesafe ranging wavelength. Technical data on this Laser and its applications as well as performance measurements are presented.

7686-47, Session 2

Progress on kW level, narrow linewidth Yb fiber amplifiers for beam combining

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Beam combining of fiber lasers has attracted much interest as a practical means to power scale fiber laser/amplifiers beyond the limitations of a single mode output from an individual fiber. Almost all of the high power demonstrations to date that deliver good beam quality after the combing process (coherent and spectral) require some linewidth control for efficient combining. The current generation of single mode, Yb-doped LMA fiber amplifiers can operate with less than 5GHz linewidth at 1kW output power, with further reductions in the linewidth likely, as the fiber technology improves. In this paper, we will present the latest data on optical properties of the latest generation of Yb-doped fiber amplifiers and the SBS threshold as a function of input seed laser linewidth, including the trade offs between different amplifier configurations such as co-pumped and counter pumped amplifiers.

7686-11, Session 3

Toward optical quality polycrystalline YAG fibers for high-energy lasers

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Traditional silica fibers currently are unlikely to be able to sustain the powers needed for future Air Force applications. The low thermal conductivity of silica makes it difficult to control thermal gradients within the fibers resulting in failure or degradation in beam quality. While some of these problems can be ameliorated by using longer fibers, this results in problems with nonlinear effects such as stimulated Raman and Brillouin scattering (SRS and SBS). Yttrium aluminum garnet (Y3Al5O12, YAG) has the potential for overcoming these problems due to 1) higher thermal conductivity, 2) reduced thermal lensing, and 3) higher SBS threshold. Polycrystalline YAG has been demonstrated to be a highly efficient and economical laser host material in slab form. Polycrystalline YAG can be doped more uniformly and at higher levels than single-crystals with no dopant loss by zone refinement, has higher fracture toughness than single-crystals, and supports higher power densities. Despite the anticipated advantages, polycrystalline YAG has

never been demonstrated in high-power fiber lasers. The development and characterization of YAG fibers for high energy laser applications is the primary goal of our research. Recent results in the production of polycrystalline YAG fibers using both powder processing and preceramic polymer approaches will be presented and discussed.

7686-12, Session 3

Comparative study of Ho^{+3} doped Y$_2$O$_3$, LuAG and YAG as gain media for diode-pumped resonant 5I7 to 5I8 laser

A. T. Word-Daniels, U.S. Army Research Lab. (United States) and Univ. of Maryland, Baltimore County (United States); G. A. Newburgh, M. Arockiasamy, M. Dubinskii, U.S. Army Research Lab. (United States)

We present spectroscopic properties and lasing results of Ho3+-doped Yttria (Y2O3), LuAG, and YAG in the wavelengths range beyond 1.6 μm. High resolution measurements of absorption and stimulated emission cross sections of Ho3+ in these hosts from 77K to 300K are reported. Laser operation based on 5I7 -> 5I8 transitions of Ho+3 in these hosts is demonstrated.

7686-13, Session 3

885-nm laser diode array pumped ceramic Nd:YAG master oscillator power amplifier system

A. W. Yu, NASA Goddard Space Flight Ctr. (United States)

We propose to develop and demonstrate technologies for the next-generation space-based laser transmitters. In this work, we will investigate pumping the ceramic Nd:YAG laser crystal with a recently commercially available 885 nm quasi-continuous wave (QCW) laser diode arrays (LDAs). GSFC is the world leader in space based lidar instruments. Since 2003, GSFC has successfully designed, built and launched ICESat and MESSENGER, with the Lunar Orbiter Laser Altimeter (LOLA) instrument for LRO to be launched in 2009. All these are 808 nm diode pumped Nd:YAG based laser transmitters. In FY03 DARPA initiated a six-year program called Super-High-Efficiency Diode Sources (SHEDS) and funded over $23M to develop laser diodes that are 80% efficient in electrical-to-optical power conversion. One of SHEDS' goals is to develop more reliable 885 nm for Nd:YAG lasers operating near 1060nm. These 885 nm diodes are tailored to directly pump the upper lasing level of Nd:YAG. When compared to traditional 808 nm pump, this will have 30% less in thermal load (or wasted heat) and will thus see a similar percentage improvement in the overall laser efficiency. The SHEDS' investment has resulted in commercial products from participating vendors that incorporated numerous innovative breakthroughs and substantial improvements in reliability and efficiency. We believe NASA can benefit greatly from this DoD technology investment and we are at the right moment to take full advantage of this opportunity to further NASA leadership role in space flight laser arena. The development of this next generation, more efficient and more reliable laser transmitter for space application will have direct impact on future Earth science missions such as DESDynI, LIST, GRACE-II and 3D-Winds which are recommended by the Decadal survey.

7686-14, Session 3

Cryogenically cooled operation of diode-pumped 3-um Er^{3+}:Y$_2$O$_3$ ceramic laser

T. V. Sanamyan, M. Dubinskii, U.S. Army Research Lab. (United States)

Sesquioxide (Y2O3, Sc2O3 and Lu2O3) single crystals and ceramics have attracted interest as laser hosts, particularly due to their ruggedness and good thermal conductivity. Another remarkable property of sesquioxide hosts is their relatively low maximum phonon energy (i.e., much lower than this of YAG), which makes them attractive as Mid-IR laser media. Here we report Er-doped Yttria (Y2O3) as highly efficient gain medium for a diode-pumped ~2.7-um laser resonantly excited into its upper laser level 4I11/2. Spectroscopy and nearly quantum defect limited laser operation of Er3+: Y2O3 are reported at 77K.

7686-15, Session 3

A face cooled Yb:YAG/SiC thin disk laser

G. A. Newburgh, A. Michael, M. Dubinskii, U.S. Army Research Lab. (United States)

We report the experimental results of a new form of thin disk laser; the Yb:YAG/SiC face cooled laser. Laser performance and thermal measurements of the 940 nm diode pumped, Yb:YAG/SiC assembly will be presented and modeling predictions made as to the power scaling potential.

7686-16, Session 4

High-brightness 975-nm surface-emitting distributed feedback laser and arrays

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Over the past few decades, diode laser technology development has achieved remarkable improvement in power, reliability and efficiency. Spectral brightness, wavelength-stabilization and spatial brightness are becoming very important for pumping of novel solid-state gain media and fiber lasers especially for efficient and power-hungry industrial and military applications. We will discuss the benefits of using 975 nm narrow-band curved grating Surface-emitting Distributed Feedback lasers for pumping fiber lasers and thin disk lasers. SE-DFB lasers with < 0.25 nm emission bandwidth, 0.07nm/°C thermal wavelength drift with >50% power conversion efficiency has been achieved with a single emitter producing >70W of CW power. Two-dimensional arrays of these lasers have been made for power scaling to achieve 1kW of power with <1nm spectral bandwidth. We will discuss the results and key advantages of using spectrally and spatially bright diodes for pumping fiber and thin disk lasers.

7686-17, Session 4

Water-cooled hard-soldered kilowatt laser diode arrays operating at high duty cycle

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High brightness laser diode arrays are increasingly found in defense applications either as efficient optical pumps or as direct energy sources. In many instances, duty cycles of 10- 20 % are required, together with precise optical collimation. System requirements are not always compatible with the use of microchannel based cooling, notwithstanding their remarkable efficiency. Simpler but effective solutions, which will not involve high fluid pressure drops as well as deionized water, are needed. The designer is faced with a number of challenges: effective heat removal, minimization of the built- in and operational stresses as well as precise and accurate fast axis collimation. In this article, we report on a novel laser diode array which includes an integral tap water cooling system. Robustness is achieved by all around hard solder bonding of passivated 940nm laser bars. Far field mapping of the beam, after accurate fast axis collimation will be presented. It will be shown that the design of water cooling channels , proper selection of package

materials, careful design of fatigue sensitive parts and active collimation technique allow for long life time and reliability, while not compromising the laser diode array efficiency, optical power density ,brightness and compactness. Main performance characteristics are 150W/bar peak optical power, 10% duty cycle and more than 50% wall plug efficiency with less than 1° fast axis divergence. Lifetime of 0.5 Gshots with less than 10% power degradation has been proved. Additionally, the devices have successfully survived harsh environmental conditions such as thermal cycling of the coolant temperature and mechanical shocks

7686-18, Session 4

High-power high-efficiency continuous-wave InGaN laser diodes in the violet, blue, and green wavelength regime

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We present new advances in green, blue, and violet InGaN laser diodes based on non-polar and semi-polar crystal orientations. We report high power, high efficiency, continuous-wave operation from single transverse mode electrically pumped laser diodes at wavelengths from 405 nm to greater than 500 nm. These devices offer dramatic improvement in size, weight, and cost over conventional gas or solid state lasers, and they may enable a variety of new applications in defense and security.

7686-19, Session 4

High-density pulsed laser diode arrays for SSL pumping

E. F. Stephens, R. Feeler, Northrop Grumman Cutting Edge Optronics (United States)

This paper documents the performance of high peak power, high density laser diode bar stacks suitable for pumping solid state laser crystals used in military and aerospace environments. The diode arrays were manufactured using a fluxless, hard solder technology that allowed for the elimination of any heat sinking material between bars. The exclusion of any heat sink material between laser diode bars creates very high stacking densities while still allowing operation up to 4% duty cycle. Data is presented for 5-, 10-, and 20-bar stacks with a bar-to-bar pitch approximately equal to the bar thickness (125 microns). The stacks utilized 225 W, 808 nm laser diode bars and thus had peak power levels approaching 5kW. Slope efficiencies, threshold currents, and wavelength shifts were comparable to standard CuW arrays up to 4% duty cycle. Stack lifetimes and outputs as a function of operating parameters were studied in detail. These high density stacks can be manufactured using bars of multiple wavelengths thus creating arrays capable of operating over very broad temperature ranges. This wavelength flexibility coupled with the fluxless hard solder process creates the ability manufacture unique arrays for diverse military & aerospace operating environments.

7686-20, Session 4

Diode laser systems for 1.8- to 2.3-μm wavelength range

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High-power diode lasers in the mid-infrared wavelength range between 1.8μm and 2.3μm have emerged new possibilities either for direct military applications or as efficient pump sources for laser sources in the 2-4μm wavelength range for infrared countermeasures. GaSb based diode

lasers are naturally predestinated for this wavelength range and offer clear advantages in comparison to InP based diode lasers in terms of output power and wall-plug efficiency.

We will present results on different MBE grown (AlGaIn)(AsSb) quantum-well diode laser single emitters and linear laser arrays, the latter consisting of 19 emitters on a 1cm long bar, emitting at different wavelengths between 1.8 and 2.3μm. Each emitter has a resonator length of 1.5mm and stripe widths of 90μm and 150μm. The distance from emitter to emitter is 500μm for both types, resulting in 20% and 30% fill factors. For single emitters the electro-optical and thermal behaviour and the wavelength tunability by current and temperature have been carefully investigated in detail in continuous wave as well as under pulsed conditions. For diode laser arrays mounted on passively cooled heat sinks by AuSn solder, more than 20W at 1.9μm in continuous-wave mode have been achieved at a heat sink temperature of 20°C resulting in maximum wall-plug efficiencies of 30%. Even at 2.2μm more than 15W have been measured, impressively demonstrating the potential of GaSb based diode lasers well beyond wavelengths of 2μm. Application driven fiber coupled single emitter modules with 600mW as well as fiber coupled bar modules with 20W have been realized.

7686-21, Session 4

Long-wavelength diode lasers optimized for high efficiency at temperatures ranging from 77K to >325K

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Motivated by a breadth of applications spanning the consumer, medical, industrial, and defense markets, the performance of hard-soldered single emitter diode lasers operating at wavelengths in the 1400 nm to 2100 nm band continues to show steady improvement. In the defense sector especially, these applications may exist within harsh operating environments. There is a demonstrated need for eyesafe laser sources which are designed for use at temperatures ranging from 77K to >325K. No single design can be optimized for use at all temperatures in this range; lasers optimized for use at one temperature aren't necessarily the best at other temperatures. Here, we report on recent advancements in the performance of nLight's eyesafe diode laser products. At 77K, nLight's cryo-optimized 1530-nm laser design achieves >70% power conversion efficiency. At 300K, our room-temperature optimized laser design achieves >45% power conversion efficiency. nLight's long-wavelength diode lasers are hard-soldered (AuSn) to expansion matched heatsinks for high reliability and to meet the needs of military and space-based applications; comparison results for devices indium soldered to copper heatsinks are provided. Results for diodes optimized for >325K operation and at other wavelengths are also presented.

7686-23, Session 4

250-W LD bar pump source with 10-GHz spectral width for rubidium vapor medium

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The diode pumped alkali vapor lasers are significantly beneficent from the developing of a new generation of high-power laser diode sources. The latest achievements in the technology of photo-thermo-refractive volume Bragg gratings opened new opportunities for the design and fabrication of compact external cavity laser diodes and bars with reflecting volume Bragg gratings as output couplers.

A new developed fiber coupled 250W LD bar source consists from 7 channels of independently stabilized commercially available bars with

standard AR-coatings at output LD mirrors. Using a specially designed reflecting volume Bragg grating, we demonstrated spectral narrowing of a single LD bar spectrum by over two orders of magnitude down to 16-18 pm at 780 nm wavelength. The volume Bragg laser bar output power exceeded 88% of that for the free-running laser bar. The spectral position of each independent LD bar was precisely tuned by means of a special method of temperature stabilization of an output volume Bragg coupler. Overall spectral width for whole system was less than 20 pm (<10 GHz).

Optical pumping of a rubidium gain medium requires fine-tuning of pumping laser emission to precisely overlap with narrow Rb absorption band. The emission spectra of the volume Bragg LD bar pumping source were tuned over a 300 pm spectral range without deteriorating the width of the laser spectra. The absorption of the pump light by Rb atoms was measured in rubidium vapor mixed with low pressure C_2H_6 buffer gas. More than 91% power of the pump source was absorbed by the low-pressure Rb vapor.

7686-24, Session 5

An overview of materials development efforts enabling mid-infrared laser sources by the Air Force Research Laboratory

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The building blocks available to the laser source designer are continuing to expand, made possible by new and improved materials. The Air Force Research Laboratory (AFRL) is working to develop laser source materials with light emission in the mid-infrared atmospheric transmission bands (2-5 µm). These efforts include the development of lasing media; of optical fiber for transport, direct lasing and isolation; and of nonlinear optical materials for wavelength shifting.

A large number of ternary II-VI ZnSe analogs, doped with Cr, Fe, and Mn, are being investigated for their direct emission in the mid-IR along with more traditional ceramics. Fiber and waveguide versions of ZnSe are being fabricated for IR beam transport and direct mid-IR lasing with suitable transition metal dopants. Chalcogenide glasses and ZBLAN have also been investigated for these functions. In addition, single mode fibers are being developed with Verdet constants greater than conventional rotator crystals for in-line optical isolation in IR fibers. These include high terbium doped aluminosilicate glasses and glass-clad fibers with cores of terbium gallium garnet and terbium scandium aluminum garnet.

Nonlinear materials are needed for generating both cw/quasi-cw laser power and highly energetic pulses in the mid-IR bands. Various bulk nonlinear optical crystals, such as $ZnGeP2$ and $CdSiP2$, which can be phased matched using their birefringence have been developed by AFRL, and they continue to be important as the only viable approach for generating high energy pulses in the mid-IR bands. More recently, nonlinear materials development efforts have focused on quasi-phase matched schemes beginning with periodically poled lithium niobate. However, lithium niobate has low transmission beyond 4 µm and has photorefractive problems that limit its IRCM usefulness. AFRL is developing several orientation-patterned semiconductors including GaAs, ZnSe, and GaP to solve these problems. These materials have extensive IR transmission and can be patterned to produce high nonlinearity. Recently, orientation-patterned GaAs was pumped by a Tm fiber laser and achieved 10 W of average power output with efficiency equal to the performance of $ZnGeP2$. In addition, two new efforts have begun to develop fiber materials that utilize Stimulated Raman Scattering to shift the wavelength of laser light to additional wavelengths in the mid-IR. The first effort is concerned with heavy-metal glass (either tellurite or gallate) fiber and the second with hydrogen-filled hollow fiber.

An overview of the work will be presented along with a description of recent progress.

7686-25, Session 5

Advances in multiwatt, multi-wavelength turn-key external cavity quantum cascade laser systems

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Recent advances in quantum cascade laser technology have been extraordinary. Multi-watt output has been demonstrated at room temperature and with wall plug efficiencies in excess of 10%. Defense and Homeland Security application requirements continue to drive such performance even higher. Daylight has developed their external cavity quantum cascade laser (ECqcL) technology into several product platforms to address these applications. In several cases, Daylight has successfully demonstrated the feasibility of their ECqcL products to satisfy the demanding requirements of military applications. Additional systems engineering and optimization of systems embodiments employing quantum cascade technology now remains. Daylight will review the state-of-the-art in multi-watt, multi-wavelength output achieved from turn-key laser systems. Daylight will also present recent performance from compact, battery operated thermal laser pointers and applications in defense and security.

7686-26, Session 5

Diode lasers operating at room temperature in 2- to 3.5-µm spectral region

T. Hosoda, J. Chen, D. Wang, G. Kipshidze, S. Suchalkin, L. Shterengas, G. Belenky, Stony Brook Univ. (United States)

The recent advancements in technology of the Type-I quantum well (QW) GaSb based lasers will be presented. Laser heterostructures for this work were grown using a Veeco GEN-930 solid source molecular beam epitaxy system on tellurium doped GaSb substrates. Performance of the room temperature operated diode lasers comprising compressively strained InGaAsSb QWs embedded into either AlGaAsSb quaternary or AlInGaAsSb barriers will be discussed. The devices operating in spectral region from 2 to 2.5 µm generate watt level output power and demonstrate power conversion efficiencies above 20% [1].

A special attention will be given to design of laser emitters with wavelength longer than 2.5 µm. Diode lasers operating at 3 µm with more than 300 mW of CW output power at room temperature will be presented [2]. The devices demonstrate room temperature threshold current densities about 200 A/cm2 and near 8% of the power conversion efficiency. Development of the corresponding single special mode lasers will be discussed. The role of the adequate hole confinement in QWs achieved by use of quinary barrier material will be extensively illustrated [3]. The diode lasers operating up to 3.5µm at room temperature employing active region with augmented hole confinement will be presented. The results of the experimental studies of the effect of carrier transport on efficiency of the mid-infrared GaSb-based diode lasers will be reported.

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7686-27, Session 5

High-efficiency high-power 2.097-mm Ho:YAG laser pumped mid-infrared ZGP optical parametric oscillation

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Mid-infrared radiations can be efficiently generated through Ho:YAG laser pumped optical parametric oscillation (OPO) in ZGP crystals. However, the Holmium laser is a quasi-three level system, the laser emission suffers re-absorption loss and the output power is sensitive to the crystal temperature due to the thermal population at the laser terminal band. More importantly, the laser extraction efficiency in such quasi three-level system can only approach unity when the pump intensity is much higher than the material's saturation intensity. This means that in the conventional single-pass or double-pass end-pump configurations, part of the pump energy has to be sacrificed in order to ensure that the non-pumped end of the crystal has high enough pump intensity to overcome the re-absorption loss as well as to maintain the high laser extraction efficiency. In this work, by using a 4-pass end-pump design, high beam quality Ho:YAG laser emission at 2.097 mm has been achieved. A maximum output power of 18.6 W has been measured at a pump power of 23.7 W in a Tm:fiber laser pumped adhesive-free bonded (AFB) YAG/Ho:YAG/YAG composite. The corresponding optical-to-optical efficiency and slope efficiency are 78.5% and 81.2%, respectively. When the laser runs in Q-switched mode, the shortest pulse width of 12.3 ns has been measured at 5 KHz. Mid-infrared OPO with wavelength tuning range from 3.1 to 6.6 mm has been also achieved in a 15-mm long ZGP crystal. The maximum output power is 1.5 W at pump power of 10 W with repetition rate of 5 KHz.

7686-28, Session 5

Multichip infrared semiconductor lasers for directed infrared countermeasures

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There is a growing demand for compact and robust light sources emitting in the 2-5 µm atmospheric window for defense and security related applications including directed infrared countermeasures (DIRCM). We report on the realization and performance of laser modules covering that wavelength range, based on two different types of semiconductor lasers.

The 2-2.5 µm atmospheric transmission window is covered by GaSb-based optically pumped semiconductor disk lasers (OPSDLs). Pumped by highly efficient fiber-coupled 980 nm emitting diode lasers, these devices deliver a continuous-wave (cw) or temporally modulated multiple-Watt output with a high beam quality (M2<3). By placing several OPSDL chips in a common resonator the output power can be scaled up to even higher values.

For the 4.5-5 µm wavelength band arrays of electrically pumped InP-based quantum cascade (QC) lasers can provide similar output power levels. Using the concept of spectral beam combining in an external cavity (EC), the output of up to eight emitters located side-by-side on a QC laser "mini-bar" is combined in a single collinear and nearly diffraction limited output beam (M2<2 in both directions). The average output power of a multiple emitter module with e.g. six QC lasers surpasses the output of a single emitter by a factor of 3 when operated in short pulse high duty cycle mode, which corresponds to a power combining efficiency of 50%. The shear optical coupling efficiency amounts to even 60%, the difference being due to thermal crosstalk between the individual emitters when operated in high average power mode.

7686-29, Session 5

High-efficiency near- and mid-IR intra-cavity OPO

J. P. Kilmer, Y. Yin, Photonics Industries International, Inc. (United States)

The near and mid-IR spectral region is of significant interest due to the atmospheric windows present in this region. Applications of lasers operating in this spectral region range from their use in remote sensing LIDAR, IR counter measures (IRCM), spectroscopy and Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) sensing systems. We report the development of a compact, highly efficient, high power intra-cavity pumped all-solid-state optical parametric oscillator (OPO) producing nanosecond pulses at kHz repetition rates with an output tunable from 1.5 microns to 3.4 microns with pulse energies up 10mJ. With our novel Intra-Cavity OPO design, pump to signal conversion efficiencies up to 65% (which is very close to its quantum efficiency) at room temperature are achievable.

7686-30, Session 6

Characterization of high-power lasers

J. M. Slater, Schafer Corp. (United States); B. E. Edwards, MIT Lincoln Lab. (United States)

This paper discusses methods for characterization of high power lasers. Specifically, these methods have been developed for the High Energy Laser Joint Technology Office (HEL-JTO) and used for independent, government-sponsored testing in the 25 and 100 kW phases of the Joint High Power Solid State Laser (JHPSSL) program. The methodology was developed in concert with the JHPSSL laser contractors, and this consultative approach has resulted in a robust measurement methodology that has provided good agreement between contractor-measured values and those measured by an independent test group. Primarily this talk addresses measurement of power and beam quality.

7686-31, Session 6

State-of-the-art of crystal growth in the United States

V. K. Simonaitis-Castillo, VKSC Consulting, Inc. (United States)

The United States had been at the forefront of technology, including crystal growth, from the mid 1900's until several years ago. The growth of crystalline materials is generally capital-intensive and low profit, with the value-added fabrication and thin film coating steps comprising the majority of the cost of the final optic. With the continuous improvements realized by scientists in foreign countries, many U.S. companies with crystal growth facilities are opting to procure material from outside the U.S. to boost profits. Compounded with Federal procurement regulations, the end result is that it has become difficult, if not impossible, to procure some mission-critical materials from U.S. sources, putting numerous DoD programs in potential jeopardy. In addition, there is a limited amount of research currently underway on new materials state-side. The history of crystal growth in the U.S. will be highlighted. Subsequently, the current state of the art of crystal growth in the United States, including available domestic materials as well as foreign-only materials, will be outlined and discussed.

7686-32, Session 6

Weight scaling model for high-power DPAL system

S. A. Mani, D. Rigdon, Schafer Corp. (United States)

Ever since Krupke et. al. proposed and demonstrated pumping alkali atoms using diode lasers in 2003, there has been lot of interest in the diode pumped alkali laser (DPAL) systems. Several researchers have been able to scale the DPAL system to the 100 watt level. We have conducted a systems level weight scaling study of a medium to high power cw DPAL system. Three different modes of operation are considered: (i) very high pressure operation (over 25 atmospheres of He) in which the absorption and emission lines of the alkali atoms are broadened sufficiently to allow for efficient pumping with off-the-shelf diodes that have line width of 2 to 3 nm. (ii) intermediate pressure regime (~ 5 atmospheres) that require diodes that are line narrowed to ~0.4 nm, and (iii) low pressure operation (~ 1 atmosphere) that require diodes that are line narrowed to < 0.1 nm for efficient pumping of pump radiation into the alkali vapor. In the latter two cases some amount of methane or ethane or some other gas would be needed to mix the two upper states rapidly while in the first case, helium is used to broaden the transition and to mix the upper states. We have considered closed-cycle transverse flowing systems with the transverse length limited by medium inhomogeneity caused by heat deposition into the gas. Weight models have been developed for each of the following sub-systems: Pump Diodes, Fluid Flow System, Thermal Management System, Optics and Diagnostics System, Instrumentation & Control System, and Electrical Power system. The results of our weight estimates for a 100 kW DPAL system will be presented.

7686-33, Session 6

Mechanical and optical properties of AFB YAG//YAG composites for waveguide lasers

H. Lee, H. E. Meissner, X. Mu, Onyx Optics Inc. (United States)

A generic YAG waveguide laser component consists of an inner cladding of undoped YAG surrounding a core of doped YAG. An important consideration is the mechanical strength of the composite structure when scaling up to high power. We report on the fracture toughness as it is related to the fracture strength when different orientations of YAG single crystals are bonded to each other to make a selection of a mechanically desirable waveguide configuration. A second equally important consideration is the refractive index difference as function of dopant concentration. We report on the difference of refractive index between Er:YAG, Nd:YAG, Yb:YAG, Tm:YAG and Ho:YAG and undoped YAG as function of dopant concentration.

We have determined the fracture toughness, KIC, of AFB YAG//YAG composites of different bonding orientations. We have found that KIC of YAG(211)//YAG(211) = 1.68 MPa*Öm that is greater than KIC of YAG(110)//YAG(110) = 1.32 MPa*Öm after they are heat-treated to a standard schedule.

The average fracture toughness, KIC, of YAG (111) mirror twins that include the twist 180° twins and flip 180° twins is 1.34 MPa*Öm after being subjected to a standard heat-treat procedure. Upon higher heat-treatment, the average fracture toughness, KIC, of YAG (111) mirror twins is increased to 1.80 MPa*Öm that is of a comparable magnitude if not greater than of that of non-composite control samples in which the KIC = 1.72 MPa*Öm. All heat-treated composite samples remain stress free.

We further elucidate the temperature dependence of the adhesive free bond mechanism between single crystal dielectric solids being London-Van der Waals forces in nature.

7686-34, Session 6

Melt growth of cesium germanium halides for nonlinear optics

S. R. Bowman, N. J. Condon, S. O'Connor, U.S. Naval Research Lab. (United States)

Cesium germanium chloride (CsGeCl3) and cesium germanium bromide (CsGeBr3) are promising new nonlinear optical materials. These materials exhibit higher nonlinearity than either KTP or LiNbO3. They also have very

broad transparency ranges extending through the visible and into the far-IR (0.35-20μm for CsGeCl3). Green harmonic generation in powder samples indicates that these materials will support broad birefringent phase matching. Further, their room temperature ferroelectric properties offer the potential for quasi-phase matching via periodic poling. Finally, acid solubility measurements indicate that these germanium halides will exhibit much better moisture stability than either KDP or beta-Barium-Borate. Nonetheless, detailed studies of these promising new materials must await the growth of large single crystals. Published reports to date have relied on solution growth, which has produced only powders and mm-scale crystals. Melt growth has the potential for producing much larger single crystals for direct integration into existing frequency agile laser systems. We will report on our recent Bridgman growth experiments and discuss the prospects for future improvements in crystal quality and size. Progress on the critical issues involving decomposition, purification, and solid-solid phase transitions will also be reviewed.

7686-35, Session 7

Power scaling analysis of fiber lasers and amplifiers based on non-silica materials

J. W. Dawson, M. J. Messerly, J. E. Heebner, P. H. Pax, A. K. Sridharan, A. L. Bullington, R. J. Beach, C. W. Siders, C. P. J. Barty, Lawrence Livermore National Lab. (United States); M. Dubinskii, U.S. Army Research Lab. (United States)

A developed formalism [1] for analyzing the power scaling of diffraction limited fiber lasers and amplifiers is applied to non-silica materials. A review of the assumptions underlying the analysis will be presented as well as the material specific results. Limits considered include thermal rupture, thermal lensing, melting of the core, stimulated Raman scattering, stimulated Brillouin scattering, optical damage, bend induced limits on core diameter and limits to coupling of pump diode light into the fiber. For conventional fiber lasers based upon silica, the single aperture, diffraction limited power limit was found to be 36.6kW. This is a hard upper limit that results from an interaction of the stimulated Raman scattering with thermal lensing. This result is dependent only upon physical constants of the material and is independent of the core diameter or fiber length. Other materials will have different results both in terms of ultimate power out and which of the many limits is the determining factor in the results. Materials to be considered in this paper include but are not limited to YAG, YAG based ceramics and phosphate based glasses. Pros and cons of the various materials and their current state of development will be assessed.

1. J.W. Dawson, M.J. Messerly, R.J. Beach, M.Y. Shverdin, E.A. Stappaerts, A.K. Sridharan, P.H. Pax, J.E. Heebner, C.W. Siders, C.P.J. Barty, "Analysis of the scalability of diffraction limited fiber lasers and amplifiers to high average power," Optics Express, vol. 16, pp. 13240-13266, (2008)

7686-36, Session 7

Recent progress on narrow linewidth linearly polarized kilowatt class CW diffraction-limited fiber lasers and amplifiers

O. Shkurikhin, N. Platonov, V. P. Gapontsev, IPG Photonics Corp. (United States)

We report on output power scaling of narrow linewidth linearly polarized fiber amplifiers and lasers to kilowatt level. Single frequency and GHz linewidth amplification in a linearly polarized amplifier is reviewed with the most recent results presented.

7686-37, Session 7

Advances and limitations in beam combination of kilowatt fiber amplifiers

J. E. Rothenberg, Northrop Grumman Aerospace Systems (United States)

Beam combination methods include active coherent phasing of tiled close packed arrays, and whole beam combination. Coherent combining requires highly accurate (< 1/10th wave) phase control, which has been demonstrated through feedback control. Tiled coherent arrays have reduced power in the central far-field lobe owing to the tiled array fill fraction. This penalty can be eliminated with whole beam combination methods, such as the use of a diffractive beam splitter in reverse, which has recently demonstrated efficiency over 90%. Tiled arrays have also been explored for passive coherent combination, but are observed to exhibit significant loss of efficiency for scaling beyond ~ 10 beams. Spectral beam combination (SBC) eliminates the fill factor penalty, but each beam must have a precisely controlled wavelength to maintain proper co-alignment, and SBC appears less scalable than the active coherent methods.

Both coherent and SBC require narrow bandwidths. Stimulated Brillouin Scattering (SBS) now limits the single frequency operation of fiber amplifiers to a few 100 W, but ~ 10 GHz linewidth has enabled > 1 kW operation. In SBC, the grating dispersion limits the bandwidth to less than ~ 1 GHz to maintain beam quality. Coherently combined beams can have arbitrary bandwidth, however the path lengths must be matched to a fraction of the coherence length. For typical high power fiber amplifiers, passive length matching allows bandwidth of 10's of GHz. Recent work is also progressing on methods to enhance the SBS threshold for single frequency kW fiber amplifiers by both fiber design and external methods.

7686-38, Session 7

Yb3+-doped fiber laser with integrated optical cooler

G. Nemova, R. Kashyap, Ecole Polytechnique de Montréal (Canada)

Heat generated in traditional exothermic solid-state lasers by Stokes shifted stimulated emission causes an increase in the temperature of the lasing medium, which causes poor beam quality and limits the average output power. The high surface-to-volume ratio in optical fiber lasers permits to compete against other high-power laser technologies such as, for example, thin-disk lasers. In spite of tremendous progress in the development of high-power fiber devices the optical intensities in fiber devices have almost reached the damage threshold of the material. In 1999, Steven Bowman suggested a radiation-balanced (athermal) laser, where lasing is accomplished by offsetting the heat generated from stimulated emission by the anti-Stokes cooling effect [1]. Unfortunately, the athermal laser requires precision control of the pump power at each point along the length of the lasing medium. The laser intensity in the athermal laser increases only linearly with the length of the medium. We propose a novel scheme for athermal Yb3+-doped fiber laser with an integrated optical cooler. In this device the heat generated in the process of Stokes shifted stimulated emission with Yb3+ ions is compensated for with laser cooling provided by anti-Stokes fluorescence of Tm3+ ions co-doped in the core of the fiber. The concentration of the Tm3+ ions is properly arranged along the length of the laser medium. The laser is pumped with two pump sources. One of the pump sources is responsible for lasing process with Yb3+ ions. The second pump provides laser cooling of the fiber with anti-Stokes fluorescence of the Tb3+ ions.

1. S. R. Bowman, IEEE J. Quantum Electron. 35, 115-122 (1999).

7686-39, Session 7

Coherent and spectral beam combining of fiber lasers using volume Bragg gratings

A. Jain, D. R. Drachenberg, O. G. Andrusyak, G. B. Venus, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); V. I. Smirnov, OptiGrate Corp. (United States); L. B. Glebov, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Compact narrow-linewidth high-power lasers with good beam quality are desired for a great number of applications. Even kW level output powers achievable from single large mode area (LMA) fiber lasers are not sufficient for many applications, making beam combining techniques a promising tool. Coherent beam combining (CBC) and spectral beam combining (SBC), using volume Bragg gratings (VBGs) in photo-thermo-refractive (PTR) glass, are presented.

Five-channel SBC with 0.5 nm spectral separation between channels and combined power >750 W has been recently reported. We will report on improvement of this technique that allows high-power SBC with 0.25 nm spectral separation of channels.

A two-channel coherently-locked Yb-doped fiber laser system with narrow linewidth (<5 pm) and near diffraction-limited beam quality is demonstrated using a novel technique that uses VBGs recorded in PTR glass as a passive multiplexer. In the presented experiment we used a VBG with peak diffraction efficiency ~ 50% and FWHM of ~ 90 pm at an incidence angle ~ 4 degrees. Output from each laser is partially diffracted by the VBG and coupled into the other laser, effectively locking the two channels. Other architectures for passive locking of two channels using VBGs will also be presented.

Methods for scaling each of these techniques to multi-kW output power and novel hybrid architectures that combine both coherent and spectral beam combining will be discussed.

7686-40, Session 7

Eye-safe laser glass development at SCHOTT

H. Li, M. J. Davis, E. H. Urruti, SCHOTT North America, Inc. (United States)

SCHOTT has developed eye safe laser glasses (LG-900 series) for laser range finder and medical/ biophotonics applications. The development covers various combinations of key ions, Er, Yb, and Cr, with and without Ce, at the controlled ratios and their perspective reduction - oxidation (REDOX) states to improve the glass lasing, thermal lensing, and thermo-mechanical stability for field applications under high repetition rate operation. This paper will focus on the glass development process, figures of merit for both lasing and thermal stability, and supporting experimental results that are fundamental to offering materials with improved laser performance.

7686-41, Session 7

CW high-power linearly polarized Raman fiber laser advances at IPG Photonics

A. Yusim, N. Platonov, V. P. Gapontsev, IPG Photonics Corp. (United States)

We report on the recent advances in scaling of CW power from single-mode, linearly-polarized Raman Fiber Lasers. 100W linearly polarized Raman Fiber Laser at 1120nm utilizing a short Raman Fiber Laser cavity is reported. Results from a 50W linearly polarized Raman Fiber Laser at 1680 nm are presented.

A systems approach for designing compact low-cost high-power fiber amplifiers

D. L. Sipes, Jr., Optical Engines, Inc. (United States)

Fiber lasers create unique opportunities for creating high energy lasers. The distributed gain and heat deposition, and the flexible resonator provide the means for scaling to high powers. In addition and perhaps more valuable is the idea that fiber lasers allow the creation of an extensible architecture: an architecture where the individual components can be researched, designed, improved and replaced independently. In order to create sources at power levels over 3kW in volumes less than .01m3/kW, weighing less than 2kg/kW at costs under $1 per Watt of fiber laser output, serious consideration first needs to be given to the underlying architecture of choice. In this presentation, several architectural constraints along with competing approaches will be presented. Preliminary results from high brightness fiber coupling, and fiber combiner designs and experiments will be presented.

High-brightness long-wavelength diode laser modules at nLight

S. Patterson, K. Price, S. R. Karlsen, M. Reynolds, A. Brown, R. J. Martinsen, P. O. Leisher, nLIGHT Corp. (United States)

Applications such as pumping eyesafe laser gain media and direct diode infrared countermeasures (IRCM) driving the development of high brightness diode modules operating in the 1400 nm to 2100 nm band. nLight's high-brightness Pearl platform leverages a conductively-cooled package format based on arrays of single-emitters. Here, we report progress on nLight's continued efforts to improve power, brightness, and efficiency. At 2080 nm, continuous-wave power in excess of 15W is demonstrated from a collimated module (5 mrad x 7 mrad beam divergence and 0.85 cm2 beam waist). In the 186x-nm to 194x-nm band, power in excess of 16 W is demonstrated as measured from the distal end of a 200 μm, 0.22 NA fiber. Recent results at 1530 nm are also reported.

Compact laser diode drivers for military rangefinder applications

D. M. Giorgi, J. Philippbar, OptiSwitch Technology Corp. (United States)

Compact and high current laser diode drivers for pumping solid-state lasers have been developed and tested. Designed to operate from a single DL123 battery or equivalent, the PLDD-120 delivers 120 A of peak current for 300 μs to a laser diode bar at 1 Hz repetition rate. Measuring only 2.1 x 0.75 x 0.78 inches and weighing 15.2 g, the unit is suited for man-portable target designation, rangefinding, illumination, and remote sensing applications. This paper will discuss the design philosophy behind this class of drivers which offer peak currents up to 200 A plus lifetime testing of eight drivers all operating at 4.5 Hz for 10M shots without a single failure or degradation in performance

Monolithic InAs/InP quantum dot mode-locked lasers and their applications

Z. Lu, J. Liu, P. J. Poole, P. Barrios, D. Poitras, S. Raymond, Z. Jiao, National Research Council Canada (Canada)

Monolithic semiconductor mode-locked lasers (MLLs) are of great interest for many photonic applications due to their compactness, mechanical stability and robustness, high potential repetition rates and low potential jitters. Recently, QD MLLs have received much attention because QD lasers have lower threshold, much better back-reflection insensitivity, faster recovery time, less chirp effects and smaller linewidth enhancement factor as compared with conventional bulk / quantum well (QW) semiconductor lasers.

In this paper, we have designed, grown and fabricated InAs/InP QD waveguides as laser gain materials and passive MLLs from a single-section monolithic Fabry-Perot cavity with repetition rate from 10 GHz to 100 GHz have been demonstrated. Femtosecond (fs) pulses with pulse duration of less than 290 fs around 1550 nm have been achieved. The optical signal-to-noise ration of the proposed QD MLLs is up to 60 dB. The average output power is larger than 100 mW at the room temperature. The lasing threshold current and the external differential quantum efficiency are as low as 17 mA and up to 40 %, respectively. Mode beating linewidth was measured to be less than 20 KHz. Its RF spectra with a 3-dB linewidth of less than 100 KHz indicated stable fs-pulses with low timing jitter since the RF spectral linewidth is broadened by both intensity noise and timing jitter. So the developed QD MLL offers a promising solution to high-bit-rate clock recovery modules and photonic analog-to-digital converters with ultra-low timing jitter. We have also discussed their potential applications for generating microwave and terahertz signals.

High-repetition-rate, narrow linewidth, and spatially controlled operation of a Q-switched Nd:YVO$_4$ laser

M. Hemmer, M. Richardson, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A Q-switched Nd:YVO4 oscillator providing up to 700 uJ of output energy at 25 kHz oscillator with a volume Bragg grating managed spectral linewidth narrower than 50 pm and a controlled spatial output profile is presented. The oscillator could provide up to 3.5 mJ of output energy in a ~50 ns pulse at 1 kHz repetition rate while maintaining a spectral linewidth narrower than 20 pm if no spatial control is applied. A systematic study of the saturation effects on spatial output profile is performed showing the limitations of Nd:YVO4 in side pumped geometry at high repetition rates.

Conference 7687: Active and Passive Signatures

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Active and Passive Signatures

7687-01, Session 1

Manifold learning for compression and generalization of euclidean invariant signatures of surface shapes

F. Pipitone, U.S. Naval Research Lab. (United States)

We describe initial results for a method useful for the efficient recognition of surface shapes in 3D data such as range images. This builds upon earlier work on Tripod Operators (TOs), a method for extracting small sets of N points from 3D surface data in a canonical way such that coordinate independent surface shape descriptions can be efficiently generated and compared. Using this method, a specific rigid object (surface shape) generates a signature which is a manifold of dimension ≤ 3 in a feature space of dimension $d = N - 3$. Then a new application of a TO on surface data generates a d-vector whose distance from the signature manifold is closely related to the likelihood of a match. In order to use TOs or similar Euclidean Invariant feature detectors for recognizing objects from large sets of known shapes, and families of shapes, we introduce the use of manifold learning to represent the signature manifolds with piecewise analytic descriptions instead of discrete point sets. In the case of families of shapes, we consider the example of generalizing the signatures of several artillery shells which have shapes which are qualitatively the same, but metrically different in a few descriptive numerical parameters. This yields a signature that is only slightly more complex than the originals, but enables the efficient recognition of a continuous family of shapes. This work is expected to be useful for the detection and/or identification of a wide variety of munitions.

7687-02, Session 1

Anomaly detection using range profile and intensity signatures from 3D LADAR data

S. C. Cain, Air Force Institute of Technology (United States)

Three dimensional LADAR data contains a wealth of information about the scene being viewed by the sensor. Extracting relevant information from this large volume of data quickly is of critical importance in many reconnaissance applications. The purpose of this research is to identify statistical features or signatures from the LADAR data in order to facilitate the identification of anomalies. The types of signatures that will be used for anomaly detection are the range profiles and intensity data. A Bayesian-based detection algorithm will be presented that uses computed signature data to determine if anomalies are present in the scene.

The LADAR data will first be processed to compute the scene intensity from each voxel, the range to target and the range depth of the scene within the voxel. The range depth is computed using a new ranging algorithm that computes the change in the pulse width measured by the LADAR system. The increase in pulse width implies the target within the pixel possess range diversity and is not simply a flat surface. The range depth, range and intensity data is then statistically analyzed to compute the statistics of the background signature. The anomaly detection algorithm finds outliers by computing the log-likelihood of each voxel. Extreme log-likelihood values are identified automatically as outliers.

The proposed detection algorithm will be tested using simulated and measured LADAR data.

7687-03, Session 1

A survey of methods for estimating surface electromagnetic properties and corresponding effects on radio frequency signatures

K. Bole, Photon Research Associates, Inc. (United States); J. Janaskie, S. Anklam, SpecTIR LLC (United States); T. Carpenter, Applied Systems Research, Inc. (United States); D. Bole, Gannett Fleming Inc. (United States)

Estimates of surface terrain electromagnetic properties can be utilized by Computational Electromagnetic Modeling (CEM) software to predict radio signal propagation loss between a transmitter and receiver. This paper will examine methods for estimating those properties, including semi-empirical models from literature, analysis of high resolution spectral imagery, and basic geology techniques. The varying precision and accuracy of these methods will be studied with the specific goal of understanding effects on the CEM code's ability to model Radio Frequency (RF) signatures in a complex terrain environment. This topic has implications on understanding and predicting the performance of RF ground sensors and systems.

7687-05, Session 2

What's in the bag? VNS version

A. I. Ifarraguerri, SAIC (United States)

No abstract available

7687-06, Session 2

2D THz signature for substance identification

V. A. Trofimov, S. A. Varentsova, Lomonosov Moscow State Univ. (Russian Federation)

The basic method of THz Time-Domain Spectroscopy (THz-TDS), which is commonly used for substance identification, is based on the analysis of the Fourier spectrum of THz radiation, passed through or reflected from a substance. However, this method has an essential disadvantage in that THz spectra of many chemical materials of interest turn out to be similar to the spectra of harmless ordinary materials. This fact results in difficulties for identification on the basis of the Fourier method.

To overcome these difficulties we develop a method for substance identification in THz frequency range, which allows to obtain the unique 2D signature of the substance. The method of identification is based on the analysis of THz and GHz spectrum dynamics (spectrogram) of medium response and has the ability not only to detect the presence of the substance in the sample but to identify it by its "spectral fingerprint", which is unique for each investigated substance. It allows to follow the dynamics of many spectral lines in one set of measurements simultaneously and to obtain the full information about the spectrum dynamics of the measured.

Under certain condition a relaxation time for excited energy levels of molecules can be determined from the spectrogram as well. This fact gives an opportunity a basis for substances identification.

The method was used for treatment of experimentally measured signals, passed through ordinary materials and selected explosives. We showed that THz and GHz spectrograms of THz pulses, passed through the hidden explosives widely differ from spectrograms of simulant themselves despite of little difference in their THz spectra.

7687-07, Session 2

Measurement and modeling of spectral signatures from layered material

G. Kniffin, S. Schecklman, J. Chen, L. M. Zurk, B. Pejcinovic, A. Timchenko, Portland State Univ. (United States)

Many polar materials have unique spectral signatures in the terahertz (THz) band, and this has suggested the possibility for non-invasive THz classification of materials. However, these signatures have primarily been obtained with transmission measurements of pure samples in laboratory settings. Recent work has suggested these pristine signatures may differ substantially from reflection spectra obtained in non-ideal geometries. In this work we present measurements and model results of THz spectra obtained from layered materials. Layered materials are commonly encountered in realistic sensing geometries, and the layer interfaces introduce coherent interference effects that modify the measured frequency spectrum.. Measurements are presented from both a time domain system, where frequency spectra are obtained from the Fourier transform of a pulse return, and from a swept-frequency vector network analyzer. Measurements from the two systems are compared to quantify the impact of the measurement system and the subsequent processing on the spectral signature. Finally, results from a model for plane parallel geometries are presented and discussed.

7687-09, Session 2

Visible through SWIR transmission, reflection, and emissivity separation techniques

A. I. Ifarraguerri, SAIC (United States)

No abstract available

7687-11, Session 3

Developing composite signatures

C. T. Hawley, National Signature Program (United States)

No abstract available

7687-12, Session 3

Laser-induced fluorescence lifetime characterization of Bacillus endospore species using time correlated single photon-counting analysis with the multi-exponential fit method

C. B. Smith, J. D. Edwards, T. J. Stewart, U.S. Army Corps of Engineers (United States)

Rapid detection of biological material is critical for determining presence/absence of bacterial endospores within various investigative programs. Even more critical is that if select material tests positive for bacillus endospores then tests should provide data at the species level. Optical detection of microbial endospore formers such as Bacillus sp. can be heavy, cumbersome, and may only identify at the genus level. Data provided from this study will aid in characterization needed by future detection systems for further rapid breakdown analysis to gain insight into a more positive signature collection of a Bacillus sp. Literature has shown that fluorescence spectroscopy of endospores could be statistically separated from other vegetative genera, but could not be separated among one another. Results of this study showed endospore species separation is possible using laser-induce fluorescence with lifetime decay analysis for Bacillus endospores. Lifetime decays of B. subtilis, B. megaterium, B. coagulans, and B. anthracis Sterne strain were investigated. Using the Multi-Exponential fit method data showed three distinct lifetimes for each species within the following ranges, 0.2-1.3 ns; 2.5-7.0 ns; 7.5-15.0 ns, when laser induced at 307 nm. The four endospore species were individually separated using principle component analysis (95% CI).

7687-13, Session 3

Characterizing greenhouse gases using the D&P spectrometer and a FLIR thermal sensor

J. W. Mirick, Signatures Support Program (United States); R. Richardson, Patrick Air Force Base (United States)

Greenhouse gases have been a subject of intense interest recently due to their impact on global climate change. Carbon dioxide from the burning of fossil fuels accounts for most of the greenhouse gas emissions to date; however, other gases like methane are becoming increasingly important. Other contributions to the greenhouse gases include refrigerants such as Freon, and the NOX family of gases. This paper will attempt to show the utility and limitations of infrared remote sensing methods to characterize and quantify point-release atmospheric greenhouse gases via a single pixel, MWIR thru LWIR D&P spectrometer, and using a broadband FLIR Long Wave Infrared broadband imaging camera.

7687-14, Session 3

Multimodal signature modeling of humans

J. M. Cathcart, S. E. Lane, B. R. Kocher, K. F. Prussing, A. M. Thomas, Georgia Institute of Technology (United States)

Georgia Tech been investigating method for the detection of covert personnel in traditionally difficult environments (e.g., urban, caves). This program focuses on a detailed phenomenological analysis of human physiology and signatures with the subsequent identification and characterization of potential observables. Both aspects are needed to support the development of personnel detection and tracking algorithms. The difficult nature of these personnel-related problems dictates a multimodal sensing approach. Human signature data of sufficient and accurate quality and quantity do not exist, thus the development of an accurate signature model for a human is needed. This model should also simulate various human activities to allow motion-based observables to be exploited. This paper will describe a multimodal signature modeling approach that incorporates human physiological aspects, thermoregulation, and dynamics into the signature calculation. This approach permits both passive and active signatures to be modeled. The focus of the current effort involved the computation of signatures in urban environments. Within the urban environment, illumination conditions can vary widely and change dynamically during the course of a day. This paper will discuss those issues and present a computational approach to computing the radiative exchange. Examples of electro-optical signatures and radar-based signatures will be presented. Video sequences of humans in a simulated urban environment will also be presented; results using these sequences for personnel tracking will be presented.

7687-15, Session 3

Hyper-Cam automated calibration method for continuous hyperspectral imaging measurements

Z. Habte, U.S. Army Armament Research, Development and Engineering Ctr. (United States); V. Farley, Telops (Canada); J. M. Romano, U.S. Army Armament Research, Development

and Engineering Ctr. (United States); D. S. Rosario, U.S. Army Research Lab. (United States); J. Gagnon, Telops (Canada)

The midwave and longwave infrared regions of the electromagnetic spectrum contain rich information which can be captured by hyperspectral sensors thus enabling enhanced detection of targets of interest. A continuous hyperspectral imaging measurement capability operated 24/7 over varying seasons and weather conditions permits the evaluation of hyperspectral imaging for detection of different types of targets in real world environments. Such a measurement site was built at Picatinny Arsenal under the Spectral and Polarimetric Imagery Collection Experiment (SPICE), where two Hyper-Cam hyperspectral imagers are installed at the Precision Armament Laboratory (PAL) and are operated autonomously since Fall of 2009. The Hyper-Cam are currently collecting a complete hyperspectral database that contains the MWIR and LWIR hyperspectral measurements of several targets under day, night, sunny, cloudy, foggy, rainy and snowy conditions.

The Telops Hyper-Cam sensor is an imaging spectrometer that enables the spatial and spectral analysis capabilities using a single sensor. It is based on the Fourier-transform technology yielding high spectral resolution and enabling high accuracy radiometric calibration. It provides datacubes of up to 320x256 pixels at spectral resolutions of up to 0.25 cm-1. The MWIR version covers the 3 to 5 μm spectral range and the LWIR version covers the 8 to 11.6 μm spectral range.

This paper describes the automated operation of the two Hyper-Cam sensors being used in the SPICE data collection. The Reveal Automation Control Software (RACS) developed collaboratively between Telops, ARDEC, and ARL enables flexible operating parameters and autonomous calibration. Under the RACS software, the Hyper-Cam sensors can autonomously calibrate itself using their internal blackbody targets, and the calibration events are initiated by user defined time intervals and on internal beamsplitter temperature monitoring. The RACS software is the first software developed for COTS hyperspectal sensors that allows for full autonomous data collection capability for the user. The accuracy of the automatic calibration was characterized and is presented in this paper.

7687-16, Session 3

The impact of the data archiving file format on the sharing of scientific data for use in popular computational environments

K. Bennett, U.S. Army Research Lab. (United States); J. Robertson, Clearhaven Technologies LLC (United States)

ARL conducted an initial study based on the performance of XML and HDF5 in three popular computational software environments. The three computational environments, MATLAB, Octave, and Python, are high-level scripting languages and computational software tools especially designed for computational processing. Although XML is a possible file format for sharing and exchanging data, the initial results of the study indicate the file format has clear limitations in a computational environment. The inability of popular computational tools to handle large XML formatted files limits the ability to process large XML formatted archived data files.

A more complete study shows the break down points of HDF5 and XML formatted files for the various popular computational tools and explores the dependencies of the performance of XML and HDF5 formatted files in popular computational environments on the hardware, operating system, and mathematical function. Along with looking at the influence of these dependencies, the study will explore the inverse file size relationship between HDF5 and XML formatted data files.

Several organizations, including the U.S. Army Research Laboratory (ARL), use both XML and HDF5 for archiving data and a mechanism for exchanging data. XML is best suited for storing "light" data, such as metadata, and HDF5 is best suited for storing "heavy" scientific data. The advantages of integrating and utilizing both XML and HDF5 for data archiving offer the best solution for signature providers and consumers to share information for computational and scientific purposes.

7687-17, Session 3

Modeling of spectral signatures using ab-initio calculations

J. W. Mirick, Signatures Support Program (United States)

Advances in quantum chemistry in the 1990's have resulted in improvements in modeling molecules and in calculating energies, transition structures, and modes of vibration, resulting in the capability to approximate vapor-phase infrared spectral signatures of chemicals using first principle calculations. These approaches provide a way of deriving signatures of vapor-phase chemicals, or gases, whose spectra may be too difficult to measure through traditional means. The purpose of this paper will be to review the limitations and accuracies in the modeling of spectral signatures using different methods and basis sets. Comparisons will be made between calculated values and laboratory measurements.

Comparisons will be made by calculating the modes of vibration and band center frequency using the Hartree-Fock (HF)methods, Moller-Plesset (MP) perturbation methods, and density functional hybrid (General Gradient Approximation) approaches with small and large basis sets. The GGA method provides the best approach to approximating electronic correlation with less computational effort, and therefore is preferred over HF and MP methods.

7687-18, Session 4

An investigation of hyperspectral imagery over Cuprite, Nevada

B. Peppin, SpecTIR LLC (United States)

No abstract available

7687-19, Session 4

The use of high spatial and spectral resolution airborne imagery for alteration mapping and waste characterization at the Comstock Lode, Nevada

D. W. Coulter, Overhill Imaging and Cartography LLC (United States)

No abstract available

7687-20, Session 4

Hyperspectral remote sensing techniques for locating geothermal resources

K. L. Jones, The Aerospace Corp. (United States)

No abstract available

7687-21, Session 4

HSI mineral mapping from airborne, outcrop, and drill-core perspectives

F. A. Kruse, Univ. of Nevada, Reno (United States); O. Weatherbee, W. Peppin, SpecTIR LLC (United States); R. Bedell, Univ. of Nevada, Reno (United States) and AuEX Ventures Inc. (United States); W. Calvin, J. Taranik, Univ. of Nevada, Reno (United States)

Hyperspectal imagery (HSI) data are well established for detailed mineral mapping from airborne and satellite systems. Overhead data, however, have substantial additional potential when used together with ground-based HSI measurements. An HSI scanner system was used to acquire airborne data, outcrop scans, and to image boxed drill core at approximately 5nm spectral resolution in 357 channels from 0.4 - 2.5mm. Analysis results using standardized hyperspectral methodologies demonstrate rapid extraction of endmember spectra and mapping of mineral distributions and abundances. A case history highlights the capabilities of these integrated datasets for developing improved understanding of relations between geology and spectral signatures.

7687-22, Session 4

Reflectance spectra of crude oils and refined petroleum products on a variety of common substrates

C. S. Allen, Northrop Grumman Information Technology-TASC (United States)

Each year, there are more than 15,000 oil spills in the United States, half of which occur on land. Timely acquisition of remotely sensed data provides one method to quickly assist in spill detection and delineation along pipeline corridors, at transportation accident sites, and at industrial facilities such as oil refineries and petrochemical facilities. The repetitive nature of satellite orbits, combined with auto-assisted data processing also facilitates regular monitoring of >200,000 miles of oil pipeline and thousands of industrial sites in the U.S.

A spectral library of hydrocarbon-substrate combinations is a necessary precursor to spectral detection of possible petroleum spills. To this end, a variety of crude oils and refined petroleum products were applied to ten common terrestrial substrates with the goal of developing a set of representative reflectance spectra for hydrocarbon-substrate combinations. The reflectance spectra varied directly with the quantity of liquid on the substrate. Liquid-saturated samples were then left to age and regularly remeasured, establishing a relationship between evaporative loss for volatile and semi-volatile products and sample reflectance. The results outline temporal windows of opportunity for detecting volatiles. They also provide a means for distinguishing water from petroleum and for distinguishing some hydrocarbons from one another based on their volatility.

7687-23, Session 5

Signatures of turbulence in atmospheric laser propagation

P. Hamlington, U.S. Naval Research Lab. (United States)

No abstract available

7687-24, Session 5

Signature science and the atmosphere

G. C. Gilbreath, U.S. Naval Research Lab. (United States)

No abstract available

7687-25, Session 5

Wavelength dependence for phase signature through a turbulent media

C. O. Font, U.S. Naval Research Lab. (United States)

No abstract available

7687-26, Session 5

FM-MRR analog transmission through scintillation

J. Duperre, U.S. Naval Research Lab. (United States)

No abstract available

Conference 7688:
Head- and Helmet-Mounted Displays XV: Design and Applications

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Head- and Helmet-Mounted Displays XV: Design and Applications

7688-01, Session 1

System integration considerations for tactical head-mounted displays

M. Sedillo, Ball Aerospace & Technologies Corp. (United States); J. Hoover II, N. Braun, G. Burnett, M. Racine, Air Force Research Lab. (United States)

As computer-use propagates across the battlefield, the necessity to effectively integrate such system components onto the human chassis becomes a fine balance between system usability and user acceptance. Additionally, researchers at the 711th Human Performance Wing have explored numerous Head Mounted Display (HMD) integration concepts for elite special operations Airmen to use in conjunction with the computer systems. Special Operations personnel prosecute mission objectives in dynamic environments requiring an agile integration solution that is equally accommodating. This report describes the research process as well as the unique concerns and results of integrating tactical HMD's for special operation forces. Issues involving variable use-cases as well as cable management will also be addressed.

7688-02, Session 1

Applications of the Scorpion color helmet-mounted cueing system

R. Atac, Gentex Corp. (United States)

The Scorpion HMCS has broken several product and price barriers which allow it to be used in both traditional and non-traditional applications. Its bright color display provides a new dimension for informational content. Users are just beginning to explore the ways color can be used in a projection display. The paper will discuss the benefits and effective use of this new dimension for information provided by color symbols. Scorpion has also broken through price and installation cost barriers that allow its use on platforms that could never have afforded a helmet mounted display. Such HMCS units are currently being used for both traditional cueing as well as unique applications in both airborne and maritime platforms. These applications are described as well as other potential roles for the Scorpion HMCS.

7688-03, Session 1

VSI digital day/night HMD development status

B. D. Foote, Vision Systems International, LLC (United States)

VSI will be presenting a discussion of the key technologies being used for the development of the next Generation Helmet Mounted Display. These technologies include displays, on helmet graphics processing, night amplification sensors and integration of the technologies. We will be discussing key performance parameters that include visual acuity, gain, resolution, latency and others. We will end the presentation with a review of the future HMD platforms and integration of key technologies to meet improved performance.

7688-04, Session 1

Wide field-of-view digital night vision head-mounted display

M. P. Browne, SA Photonics (United States); B. D. Foote, Vision Systems International, LLC (United States)

SA Photonics has partnered with Vision Systems International for the development of an innovative wide field of view digital night vision head mounted display (HMD). This HMD has an 80 degree field of view and has been designed to minimize weight, peripheral obscuration and forward projection. This HMD has been designed with maximum pilot utility in mind, with easily stowable eyepieces that do not impact the center of gravity of the HMD.

VSI's Zero A/C Integration enables the digital night vision HMD to be integrated with legacy aircraft and provide symbology overlay and recording without the need for an expensive drive electronics box. Aircraft information is obtained via a standard connector to an aircraft databus and a small inline electronics box provides image generation and recording.

The night vision sensors on this HMD are digital, which will provide for a number of advantages, including zero-halo performance, recording of imagery, symbology overlay, scintillation reduction and contrast enhancement. Because the sensors are digital, they can be located right above the pilot's eyes removing any hyperstereoopsis.

7688-05, Session 1

IR diver vision for turbidity mitigation

J. A. Milam, 3-D Imaging, Inc. (United States)

Commercial, forensic, and military divers often encounter turbid conditions which reduce visibility to zero. Under such conditions, work must be performed completely blind. The darkness resulting from high levels of turbidity is complete, and can be dangerous as well as disorienting. Such darkness can even occur near the surface on a bright and sunny day. Artificial underwater lighting is of no use in such situations, as it only makes matters worse (similar to the use of high beam headlights in dense fog). Certain wavelengths of infrared (IR) light have the ability to penetrate this underwater "fog," and thus form the basis of the current development.

Turbidity results from clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton and microscopic organisms suspended in water.

The IR Diver Vision system described herein consists of a standard commercial diving mask of any of several configurations whereby an IR light source, IR video camera, video display, and power source may be integrated within or attached to the mask. The IR light source wavelength is compatible with the spectral bandwidth of the video camera. The camera field-of-view (FOV) is matched to the video display in order to provide a unity magnification and hence prevent diver ocular fatigue. The IR video camera, video display, power source and controls are compatible with extended use in a submarine environment. Some such masks will incorporate tilt/heading sensors and video indicators. 3-D Imaging, Inc. has developed prototypes and has patents pending on such devices.

7688-06, Session 1

The supplementary device for color deficiencies

Y. Chen, T. Liao, Instrument Technology Research Ctr. (Taiwan)

According to the statistics, there is about 10% of global population whom suf-fering from color deficiencies, especially deuteranomaly and protanomaly (whom have difficulty with discrimination red and green hues). Those whom suffered of color deficiencies, their field of carrier were restricted and were frustrated during their childhood education. There are many optical adjusting eye glasses in the market. Though its light-weight is just like sun glasses, but wearing it decreases the brightness of the viewing sight, and might became a problem wearing it in the night. In this paper, we present a supplementary device which combined the Head mount displayer and an image sensor. By using the hardware digital color adjustment method which based on high speed FPGA (field programmable gate array) device, the user can see the adjusted vision through the displayer without decreasing any brightness of the sight.

7688-07, Session 2

Approach to a new version of night vision goggles

G. S. Saini, Air Force Research Lab. (United States)

Night vision goggles are devices that allow an image to be seen even in almost complete darkness. Such an image is not viewable by the naked eye and even if some symptom is noticed in partial darkness, it is very weak and is not intelligible. As such the night vision goggles help the fighters to more efficiently execute the night operations. The workhorse of the current night vision goggles is itself a device called image intensifier tube (IIT). IIT is based on an outdated technology, has analog output, and has certain drawbacks such as limited spectrum, limited image processing and transmission capabilities. Recent progress in the photodiodes, focal plane arrays, read out integrated circuits, and micro displays has made it possible to produce a more capable and compact solid state digital version of night vision goggles. This paper will discuss the work being done in this field.

7688-08, Session 2

Solid-state electrochromic variable transmission eyewear

H. Demiryont, K. C. Shannon III, Eclipse Energy Systems, Inc. (United States)

There is a need for variable transmission technology for Goggles, Spectacles, and visors for Helmet-Mounted Displays (HMDs). At present, most HMD's do not allow the pilot to control the transmission level of a flight visor while transitioning from high to low light levels throughout flight. Sunglasses are often used for non-HMD conditions but become impractical for HMD use. For individuals moving from high to low brightness levels, momentary blindness is an issue in both recreational sports and military applications. A user-controlled or automatically controllable variable-transmittance lens is a possible solution. The Eclipse Visible Electrochromic Device (EclipseECD) is well suited for these light modulation applications. The EclipseECD modulates light intensity by changing the absorption level under an applied electric field. The optical density may be continuously changed by varying voltage allowing for analog instead of digital (on/off) light levels. This all solid-state ECD system can be deposited on flat, curved, rigid or flexible substrates, eg. PET, PC, etc. The low-temperature deposition process enables direct application to polymer lenses and HMD flight visors. Additionally, the coating is easily manufactured; can be trimmed, has near spectral neutrality and fails in the clear (bleached) condition. This paper discusses efforts to make the devices more field survivable, including ballistic characteristics and power consumption advances.

7688-09, Session 2

Active matrix organic light emitting diode (AMOLED)-XL performance and life test results

D. A. Fellowes, M. V. Wood, U.S. Army Night Vision & Electronic Sensors Directorate (United States); A. Ghosh, eMagin Corp. (United States)

The US Army and eMagin Corporation established a Cooperative Research and Development Agreement (CRADA) to characterize the ongoing improvements in the lifetime of OLED displays. This CRADA also called for the evaluation of OLED performance as the need arises, especially when new products are developed or when a previously untested parameter needs to be understood. In 2006, eMagin Corporation developed long-life OLED-XL devices for use in their AMOLED microdisplays for head-worn applications. Through Research and Development programs from 2007 to 2009 with the US Government, eMagin made additional improvements in OLED life and developed the first SXGA (1280 X 1024 triad pixels) OLED microdisplay. US Army RDECOM CERDEC NVESD conducted life and performance tests on these displays, publishing results at the 2007, 2008, and 2009 SPIE Defense and Security Symposia. Life and performance tests have continued through 2009, and this data will be presented along with a recap of previous data. This should result in a better understanding of the applicability of AMOLEDs in military and commercial head mounted systems: where good fits are made, and where further development might be desirable.

7688-10, Session 2

In-flight evaluation of an Optical Head Motion Tracker II

K. Tawada, Shimadzu Corp. (Japan)

We have presented a new approach for Optical HMT (Head Motion Tracker) in flight test at last year (Proc. SPIE 7326, 73260L-4, 2009). In existing Magnetic HMT, it is inevitable to conduct pre-mapping in order to obtain sufficient accuracy because of magnetic field's distortion caused by metallic material around HMT, such as cockpit and helmet. Optical HMT is commonly known as mapping-free tracker; however, it has some disadvantages on accuracy, stability against sunlight conditions, in terms of comparison with Magnetic HMT. We have succeeded to develop new Optical HMT, which can overcome particular disadvantages by integration with two area cameras, LED markers, image processing techniques and inertial sensors with simple algorithm in a laboratory. We have also reported some experimental results conducted in a laboratory, which proves good accuracy even in the sunlight condition. This time, we show actual performance of the Optical HMT in flight test, including evaluation of stability against sunlight.

7688-11, Session 3

Perceptual and cognitive effects on the use of helmet-mounted displays due to external operational factors

T. H. Harding, C. E. Rash, U.S. Army Aeromedical Research Lab. (United States)

This paper addresses the human component of the human-machine interface and the effects of operational stressors on the user as a system operator. Discussions will strive to link operational stress factors to perception, cognition, and human performance errors and

their implications for the design of combat systems - including helmet-mounted displays (HMDs). While many operational stressors can be self-imposed (e.g., fatigue, medication use and smoking), this discussion will focus on environment-related (external) stressors. Generally these factors are characteristics of the aviation or ground environment that require unique countermeasure development versus being under the direct control of the user. These include altitude, noise, vibration, thermal extremes and ambient lighting. Thus, it becomes incumbent upon HMD designers to be cognizant of these environmental stressors and understand how the user will perform when exposed to these conditions.

7688-12, Session 3

Cognitive considerations for helmet-mounted display design

G. Francis, Purdue Univ. (United States); C. E. Rash, U.S. Army Aeromedical Research Lab. (United States)

The primary goal of using helmet-mounted displays (HMDs) is to increase performance. To meet such a goal, there must be an accurate transfer of information from the HMD to the user; and this transfer must occur at appropriate times. Ideally, an HMD would be designed to accommodate the abilities and limitations of users' cognitive processes. It is not enough for the information to be displayed (visually, auditorially, or tactually); the information must be perceived, attended, remembered, and organized in a way that guides appropriate decision-making, judgment, and action. Following a general overview, we explore specific subtopics of cognition, including perception, attention, memory, knowledge, decision-making, and problem solving. We then consider a variety of topics that have special interest for HMD design, including characterizations of human error, the effect of stressors on cognition, situation awareness, and workload.

7688-13, Session 3

Performance and comfort of monocular head-mounted displays in flight simulators

M. P. Browne, SA Photonics (United States); M. Winterbottom, Air Force Research Lab. (United States)

Monocular imagers are ubiquitous in the military, being used in both head mounted displays (HMDs) for aviation (JHMCS, DASH, IHADSS), dismounted infantry (Land Warrior, Felin), as well as other applications. Although these devices have been used successfully for many years, and provide critical performance advantages, there has been anecdotal evidence of user discomfort and other issues when using monocular imaging devices. With the introduction of the IHADSS in particular, training issues with the monocular device were well documented.

An initial study of imaging modalities for use in an aviation simulator showed that not only was the monocular condition the most uncomfortable, it also resulted in poorer operator performance for a simplified targeting task when compared to analogous binocular and on-screen conditions. Additionally, other experiments have shown a reduction in visibility of monocularly presented symbology under some circumstances. Our current research examines whether this reduction in performance is dependent on eye dominance and if it can be reduced or removed through training. We investigated the amount of time it took operators to make correct decisions on a simplified targeting task which also involved a simple number matching task using a see-through head mounted display and a large screen display representing an "out the window" view in a flight simulator. The implications of this research and potential advantages of binocular/biocular HMDs over monocular HMDs are discussed.

7688-14, Session 3

Reducing system latency errors in training systems using helmet-mounted displays (HMDs)

D. A. Vincenzi, Naval Air Warfare Ctr. Training Systems Div. (United States); E. L. Blickensderfer, Embry-Riddle Aeronautical Univ. (United States); J. E. Deaton, Florida Institute of Technology (United States); B. Williams, R. Pray, RPA Electronics Design, LLC (United States); T. J. Buker, Florida Institute of Technology (United States)

Future military aviation platforms such as the proposed Joint Strike Fighter F-35 will integrate helmet mounted displays (HMDs) with the avionics and weapon systems to the degree that the HMDs will become the aircraft primary display systems. In turn, training pilots' flight skills using the HMDs will be essential. In order to train these skills using simulation based training, improvements must be made in the integration of HMDs with out-the-window simulations. Currently, problems such as latency errors generate simulator sickness and other distractions during training with HMD simulator systems. Previous research has used Kalman predictive filter algorithms to mitigate the latency errors in these systems. While this approach has yielded some success, more work is needed both to improve strategies to reduce latency errors as well as to include the user perspective as a measured variable during test and evaluation of latency reduction strategies. The purpose of this paper is to twofold. First, the paper describes a new method/testbed to assess perceived latency from the user perspective. Second, the paper describes use of the testbed to examine the efficacy of an innovative strategy that combines a customized Kalman filter with a neural network approach to reduce latency errors. Results indicate that the combined approach reduced latency errors significantly when compared to baseline data and the traditional Kalman filter. Reduced latency errors should ease some simulator sickness symptoms. Implications for training systems will be discussed.

7688-15, Session 3

Aviator's Night Vision System (ANVIS) in Operation Enduring Freedom (OEF): user acceptability survey

K. L. Hiatt, Army Research Institute of Environmental Medicine (United States); C. E. Rash, U.S. Army Aeromedical Research Lab. (United States)

In 1973, the U.S. Army adopted night vision devices for use in the aviation environment. These devices are based on the principle of image intensification (I2) and have become the mainstay for the aviator's capability to operate during periods of low illumination, i.e., at night. In the nearly four decades that have followed, a number of engineering advancements have significantly improved the performance of these devices. The current version, using 3rd generation I2 technology is known as the Aviator's Night Vision Imaging System (ANVIS). While considerable experience with performance has been gained during training and peacetime operations, no previous studies have looked at user acceptability and performance issues in a combat environment. This study was designed to compare Army Aircrew experiences in a combat environment to currently available information in the published literature (all peacetime laboratory and field training studies) and to determine if the latter is valid. The purpose of this study was to identify and assess aircrew satisfaction with the ANVIS and any visual performance issues or problems relating to its use in Operation Enduring Freedom (OEF). The study consisted of an anonymous survey (based on previous validated surveys used in the laboratory and training environments) of 86 Aircrew members (64% Rated and 36% Non-rated) of an Aviation Task Force approximately 6 months into their OEF deployment. This group represents an aggregate of >94,000 flight hours of which ~22,000 are ANVIS and ~16,000 during this deployment. Overall user acceptability of

ANVIS in a combat environment will be discussed.

7688-16, Session 4

Single- and multiple-event temporal response characteristics of nongated generation-III image intensified systems

M. Bell, Duke Univ. (United States); J. P. Estrera, L-3 Electro-Optical Systems (United States); M. Johnson, Texas A&M Univ. (United States)

The output brightness response of nongated image intensified systems are examined temporally in this paper. Generation III image intensified (I2) tubes using the P43 and P20 phosphors were tested for image persistence, minimum event detection, and minimum event separation, where "event" refers to a burst of light of determined duration and brightness. Persistence tests showed both consistencies and inconsistencies with previously published data and suggests that both types of I2 tube phosphor screens exhibit multiple stages of temporal decay. The minimum event detection showed the I2 tubes are capable of detecting pulses with durations in the low microsecond region and suggest with a faster experimental temporal test setup that I2 tubes may have the capability to operate in the nanosecond regime. Finally, the multiple burst testing shows and characterized the complex nature of nongated I2 power supply interacting with I2 tube when the full I2 electro-optical system is exposed to multiple, rapid (high temporal rate) flashes of light.

7688-17, Session 4

Graphical user interface concepts for tactical augmented reality

C. Argenta, A. Murphy, Applied Research Associates, Inc. (United States); J. L. Hinton, BAE Systems (United Kingdom); J. Cook, T. Sherrill, Applied Research Associates, Inc. (United States)

Applied Research Associates, Inc. and BAE Systems are jointly developing a wearable augmented reality system under the DARPA ULTRA-Vis* effort. This system supplements the dismounted warrior with superior awareness in dynamic urban combat environments by incorporating a full color see-thru holographic waveguide with forty degree field of view. Our system is designed to be unobtrusive for operational maneuvers while performing full position, pose, and head tracking. This system will enable warriors to mark-up the battle-space with graphical control measures and mil-standard symbology identification of friendly force positions and enemy/target locations with an accuracy within <1m at 100m. Given this accuracy and capability, we have designed unique user interface and situational awareness graphical representations which are highly intuitive, non-disruptive, and always tactically relevant. Our augmented reality display provides dynamic real-time painting of symbols on viewed real objects, a pose-sensitive 360° representation of unseen objects and directions, and visual feedback for a variety of system activities.

We have applied best human-factors practices, system engineering expertise, cognitive task analysis, and experience with cockpit heads-up displays and other tactical soldier systems to design effective strategies for presenting real-time situational awareness data to the military user without distorting their natural senses and perception. In this paper, we present the requirements we have discovered for presenting information within a see-thru display in combat environments, challenges we have come up against in designing a suitable visualization capability, and our solutions which have enabled us to bring real-time iconic command and control to the tactical user community.

* Sponsored by DARPA under the ULTRA-Vis Program, contract # FA8650-09-C-7909. DISTRIBUTION STATEMENT A: Approved for public release, distribution is unlimited. Abstract approved by DARPA 9/11/2009

7688-18, Session 4

Head up display analysis using MAPLE

J. A. Betancur Ramírez, Univ. EAFIT (Colombia)

This paper describes a Helmet Mounted display (HMD) based on an augmented reality system applied to car technologies, using the software MAPLE to analyze the system stability during specific environments in order to understand how the optic parameters are affected by the surrounding conditions. The objective of this paper is segmented into two parts, the first one is the recognition of many different optic parameters involved in such systems, which are analyzed using the mixing of a mathematical model and many measurement systems, where the principal idea was to describe the ratios between both aspects; and the second one is the comprehension of how all those parameters are related with the human perception; I found that parameters like FOV, eye relief and MTF are directly related with the image size, and contrast threshold, additionally I conclude that the effectiveness of the system is determinate by the optic elements used and the system array of lens, finally I found many lens structure that could reduce the aberration amounts present in this kind of systems; all these considerations are focused on the developing of a car gadget, but the application of this knowledge is unlimited in optic systems.

Conference 7689: Enhanced and Synthetic Vision 2010

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Enhanced and Synthetic Vision 2010

7689-01, Session 1

Beyond traffic depiction: conformally integrating the conflict space to support level 3 situation awareness

J. Tadema, Netherlands Defence Academy (Netherlands); E. Theunissen, Technische Univ. Delft (Netherlands); K. Kirk, General Atomics Aeronautical Systems, Inc. (United States)

Synthetic Vision (SV) systems show a computer generated image of the environment with a quality that is independent of actual visibility conditions. The premise is that safety will increase because the timely detection of hazards is no longer impaired by (poor) visibility. Ample research data is available that supports this claim for hazards that are static such as terrain and obstacles. However, for traffic this is not the case. Many conflict geometries are possible that will lead to a loss of separation and a collision hazard without the intruding aircraft ever coming within the field of view used to render the synthetic environment. Research has addressed this issue by designing exocentric views for the depiction of traffic, providing a perspective all-around view relative to ownship. Rather than using a different viewpoint, the research described in this paper explores the addition of conformally integrated traffic probes into an egocentric SV Primary Flight Display (PFD). The underlying thought is that, although the traffic that is predicted to cause a future loss of separation may not lie within the field of view, the location where the loss of separation is predicted to occur always will. Hence, rather than focusing on the depiction of traffic which contributes to level 2 Situation Awareness (SA), the concept pursues spatially integrated depiction of the airspace where a loss of separation is predicted, contributing to level 3 SA. Depending upon the concept of operation, the traffic probe can be configured using either a pilot-selectable Assured Normal Separation Distance (ANSD) or a Self Separation Threshold (SST). The paper will start with a discussion on the integration of the data from the two-dimension traffic probe into the SV PFD. The advantages of the concept will be illustrated using several traffic conflict scenarios, including an overtaking scenario involving unmanned aircraft. Given that unmanned aircraft may be markedly slower than manned aircraft which operate within the same airspace, a spatially integrated depiction of conflicting airspace can help to preserve safety in classes of airspace that accommodate both manned and unmanned aircraft.

7689-02, Session 1

Enhanced vision for all-weather operations under NextGen

L. J. Kramer, R. E. Bailey, NASA Langley Research Ctr. (United States)

Two fixed-based simulation experiments were recently conducted in NASA Langley Research Center's Integration Flight Deck simulator to investigate the use of Synthetic Vision (SV) and Enhanced Vision (EV) technologies as enabling technologies for Equivalent Visual Operations (EVO) in the emerging Next Generation Air Transportation System (NextGen) operating environment. Both experiments evaluated the complementary use of SV and EV technologies on a Head-up Display (HUD) for all-weather operations. Experiment One evaluated the utility, acceptability, and usability of integrated/fused EV and SV technologies and its effect on two-crew operations. This work began the development of an all-weather commercial aviation operations capability, approaching that which might create an EVO capability, although the experiment employed a natural vision segment where the flight crew was required to transition to natural vision no lower than 100 ft above the touchdown zone elevation. Based on results from Experiment One, the second experiment evaluated the feasibility of a fused synthetic/enhanced vision system (S/EVS) on a HUD to provide for all weather (visibility)

landing capability without the need for a visual approach segment and the interaction between EVS and peripheral cues for terminal area and surface operations. This paper compares and contrasts pilot approach and landing performance while flying a S/EVS HUD, with (Experiment One) and without (Experiment Two) a natural vision segment during reduced visibility conditions. The results are discussed in terms of emerging all-weather operations requirements and technologies. Pilot recognition of and reaction to non-normal (e.g., failure) flight conditions while using a fused S/EVS HUD will also be discussed. The pilot's awareness and reaction to these non-normal events (i.e., failure conditions) serve as critical determinants in the underlying safety of all-weather operations.

7689-03, Session 1

Part-task simulation of synthetic and enhanced vision concepts for lunar landing

J. J. Arthur III, R. E. Bailey, E. B. Jackson, J. R. Barnes, S. P. Williams, NASA Langley Research Ctr. (United States)

During Apollo, the constraints placed by the design of the Lunar Module (LM) window for crew visibility and landing trajectory were "a major problem" (NASA TN D-4131). Trajectories were tailored to provide crew visibility using nearly 70 degrees look-down angle from the canted LM windows. Apollo landings were scheduled only at specific times and locations to provide optimal sun light on the landing site.

The complications of trajectory design and crew visibility are still a problem today. Practical vehicle designs for lunar lander missions using optimal or near-optimal fuel trajectories render the natural vision of the crew from windows inadequate for the approach and landing task. Further, the sun angles for the desirable landing areas in the lunar polar regions create visually powerful, season-long shadow effects.

Fortunately, Synthetic and Enhanced Vision (S/EV) technologies, conceived and developed in the aviation domain, may provide solutions to this visibility problem and enable additional benefits for safer, more efficient lunar operations.

Piloted simulation evaluations have been conducted to assess the handling qualities of the various lunar landing concepts, including the influence of cockpit displays and the informational data and formats. Evaluation pilots flew various landing scenarios with S/EV displays. For some of the evaluation trials, a small head-worn, monochrome monocular display, coupled with head tracking, was worn. The head-worn display scene consisted of S/EV fusion concepts.

The results of this experiment and pilot comments and analyses will be presented. The data are analyzed to ascertain, in part, if SV and EV technologies can supplement or replace natural vision for lunar landing vehicles.

7689-04, Session 1

Standardization of databases for AMDB taxi routing functions

C. Pschierer, A. Sindlinger, Jeppesen GmbH (Germany)

Input, management, and display of taxi routes on airport moving map displays (AMM) have been covered in various studies in the past. The demonstrated applications are typically based on Aerodrome Mapping Databases (AMDB). Taxi routing functions require specific enhancements, typically in the form of a graph network with nodes and edges modeling all connectivities within an airport, which are not supported by the current AMDB standards. Therefore, the data schemas and data content have been defined specifically for the purpose and test scenarios of these studies.

A standardization of the data format for taxi routing information is a

prerequisite for turning taxi routing functions into production. The joint RTCA/EUROCAE special committee SC-217, responsible for updating and enhancing the AMDB standards DO-272 and DO-291, is currently in the process of studying different alternatives and defining reasonable formats.

Requirements for taxi routing data are primarily driven by depiction concepts for assigned and cleared taxi routes, but also by database size and the economic feasibility. Studied concepts are similar to the ones described in the GDF (geographic data files) specification, which is used in most car navigation systems today. They include

- A highly aggregated graph network of complex features
- A modestly aggregated graph network of simple features
- A non-explicit topology of plain AMDB taxi guidance line elements

This paper introduces the different concepts, their advantages and disadvantages, and the prototypical evaluation.

7689-05, Session 1

INVIS: integrated night vision surveillance and observation system

A. Toet, M. A. Hogervorst, J. Dijk, R. van Son, TNO Defence, Security and Safety (Netherlands)

We present the design and first field trial results of the INVIS integrated night vision surveillance and observation system. The INVIS is an all-day all-weather navigation and surveillance tool. It combines a three-band nightvision sensor suite, consisting of two digital image intensifiers and a thermal (LWIR) camera, with a 3D digital position information system. The night vision sensor suite is sensitive in the visual (400-700 nm), the near-infrared (700-1000 nm) and the longwave infrared (8-14 μm) bands of the electromagnetic spectrum. The optical axes of all cameras are aligned. Image quality of all individual sensor signals can be enhanced through Dynamic Noise Reduction and Superresolution. The quality of the thermal image can be enhanced through Scene-Based Non-Uniformity Correction (SBNUC) and intelligent clustering and thresholding. The combination of the two intensified images is used to represent the resulting multiband nightvision image in realistic daytime colors, using the Color-the-Night color mapping principle. This mapping can also be deployed to enhance the visibility of thermal targets that are camouflaged in the visual range. The position information system is capable of displaying daytime and tactical synthetic 3D views of the environment and provides environment-specific cues for the daytime color mapping algorithm. A first field trial of the system was conducted at the Marnehuizen MOUT training site.

7689-06, Session 1

An evaluation test bed for enhanced vision

H. Doehler, N. Peinecke, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The DLR Institute of Flight Guidance is involved in many projects dealing with the development of new concepts for flight procedures and pilot assistance functions. This includes especially the topic of enhanced vision (EVS), where processed data from radar and infrared sensors is utilized to augment the pilot's vision. For evaluating these concepts extensive flight testing has been conducted and results have been published during the last years. Now, DLR has combined its expertise in the field of high performance sensor simulation on the one hand side, together with the visual simulation for its generic cockpit simulator, on the other hand. Sensor simulation of imaging radar, lidar, infrared, etc., is based mainly on the application of high performance functions of modern computer graphics hardware (vertex and fragment shaders). The direct combination of these functions with the "outside-vision" software, which is now based on exactly the same terrain and object geometry, delivers sensor data that perfectly correlate to the visual channel. This combined simulation environment will be the basis for various evaluation trials within the near future, including simulation trails for fixed-wing and

rotary-wing applications.

The paper presents the implemented software and hardware architecture of the cockpit's visual simulator and its coupling to the sensor simulation test-suite. First results of recently conducted simulation experiments including the evaluation of new proposed flight procedures, which apply EVS technology, are given.

7689-07, Session 2

New adaptive algorithms for real-time registration and fusion of multimodal imagery

J. Heather, J. R. E. Sadler, M. Bolsover, M. I. Smith, Waterfall Solutions Ltd. (United Kingdom)

Accurate image registration is a pre-requisite for most systems utilising two or more imaging sensors. This can easily be achieved offline in the laboratory but maintaining registration accuracy in the field is a significant challenge. This paper presents an efficient image registration algorithm capable of producing live updates during real-time operation. The algorithm is fully automatic and constrained to ensure reliable operation with minimal operator supervision. Robustness to large initial alignment errors is demonstrated using a selection of challenging multi-modal image sets. In addition, a novel adaptive image fusion algorithm for maximising fused image quality in the presence of sensor noise is presented. The paper concludes by describing how both algorithms were successfully integrated into a prototype real-time image fusion system.

7689-08, Session 2

Image enhancement on the INVIS integrated night vision surveillance and observation system

J. Dijk, A. Toet, M. A. Hogervorst, TNO Defence, Security and Safety (Netherlands)

We present the design and first field trial results of the INVIS integrated night vision surveillance and observation system, in particular for the image enhancement techniques implemented. The INVIS is an all-day all-weather navigation and surveillance tool, combining a three-band nightvision sensor suite, consisting of two digital image intensifiers and a thermal (LWIR) camera, with a 3D digital position information system. The night vision sensor suite is sensitive in the visual (400-700 nm), the near-infrared (700-1000 nm) and the longwave infrared (8-14 μm) bands of the electromagnetic spectrum. The optical axes of all cameras are aligned. Image quality of all individual sensor signals is enhanced through Dynamic Noise Reduction and Super Resolution. The quality of the thermal image can be enhanced through Scene-Based Non-Uniformity Correction (SBNUC) and intelligent clustering and thresholding. In this way, hot objects such as people and cars can be emphasized. The images are fused using natural tone mapping techniques. After that, the contrast in the image can be improved using Local Adaptive Contrast Enhancement. All techniques applied on the single sensor do not change the range of the sensor very drastically. This is needed for the fusion process. As contrast enhancement changes the dynamic range much, this is applied after the image fusion. In the paper, results are shown of both the separate enhanced imagery and on the fused imagery. These results indicate that the image enhancement techniques have an added value for this type of image fusion systems.

7689-09, Session 2

An efficient color transfer algorithm for recoloring multiband night vision imagery

G. Li, S. Xu, Changchun Institute of Optics, Fine Mechanics and Physics (China)

A color transfer method is presented to give fused multiband nighttime imagery a natural daytime color appearance in a simple and efficient way. Instead of using the traditional nonlinear l   space, the proposed method transfers the color distribution of the target image (daylight color image) to the source image (fused multiband nighttime imagery) in the linear YCBCR color space. The YCBCR transformation is simpler and more suitable for image fusion compared to the l   conversion. The YCBCR transformation can be extended into a general formalism. And the paper mathematically proves that, for color transfer, using color spaces conforming to this general YCBCR space framework can produce same recoloring results as using the YCBCR space. Experimental results demonstrate that the proposed color transfer method works surprisingly well for transferring natural color characteristics of daylight color images to false color fused multiband nighttime imagery, and moreover, can also be successfully applied to recoloring a variety of color images.

7689-10, Session 2

Correcting hyperstereopsis in a helmet-mounted vision system

N. Peinecke, S. Schmerwitz, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

When used in conjunction with helmet mounted displays stereo camera views can provide invaluable advantages in, for example, aviation uses. One of the most common setups is to mount cameras to both sides of the pilot's helmet. However, since these cameras posses a larger disparity than the eyes distances to perceived objects are misinterpreted by the pilot. This may cause irritations, even sickness when combined with enhanced displays. Even in the best case the magnified disparity may lead to exaggerated distance estimations.

In this paper simple computations are presented that can correct hyperstereopsis ``on the fly". With the availability of fast computer hardware carrying out these computations in real time comes into reach. Furthermore, we sketch a series of experiments to evaluate the effectiveness of our approach.

The key idea is to use the well known stereo correspondence formula. If pairs of mathing points are known in left and right views respectively the disparity can be corrected. The problem can then be restated as a problem of finding correspondences. We use a simple correlation approach. If the method fails, i.e., if the local image contrast is not sufficient to match a point to its sibling, the disparity needs no correction there, since stereo correspondence can only be perceived for higher contrast.

To demonstrate and evaluate the approach we implemented a simplified flight simulator. Therein, test personal is asked to follow a marked course of obstacles while recording the time points when entering curves. That way, we can infer the impact of hyperstereopsis and corrected hyperstereopsis on 3D perceptionof distances to the obstacles.

7689-11, Session 2

A method for generating enhanced vision displays using OpenGL video texture

K. L. Bernier, The Boeing Co. (United States)

Enhanced Vision (EV) is typically derived from low light level CCD, infrared, and millimeter wave radar imagers, and presented on head-up or head-mounted displays as a world-conformal overlay. This conformal imagery may be generated at video frame rates with two-frame latency using standard image capture and OpenGL video texturing techniques. This paper provides efficient implementation methods for geometric distortion correction and OpenGL video texture overlay for generating this conformal imagery from distributed aperture multi-modal camera video streams.

7689-13, Session 3

Collision avoidance with integrity using raw measurements in the automatic dependent surveillance - broadcast

M. Uijt de Haag, S. Vana, Ohio Univ. (United States)

This paper discusses an alternative ADS-B implementation that uses available provisions (Mode-S and GPS receivers) and existing GPS algorithms and techniques. This alternative has many advantages over the current ADS-B implementation, especially with respect to integrity of the solution. The paper will describe the methodology, its advantages, simulation results and implementation issues.

7689-14, Session 3

Synthetic observer approach to multispectral sensor resolution assessment

A. R. Pinkus, D. W. Dommett, Air Force Research Lab. (United States); H. L. Task, Task Consulting (United States)

Resolution is often provided as a key parameter addressing the quality capability of a sensor. One approach to determining the resolution of a sensor/display system is to use a resolution target pattern to find the smallest element that can be "resolved" using the system, which requires a human in the loop to make the assessment. This paper investigates use of a custom designed software approach to generate an effective resolution value for a sensor using Landolt Cs. Images were analyzed using the software to determine the orientation of the C at each distance, which resulted in a probability of correct orientation detection curve as a function of viewing distance. This generated a "resolution" for the sensor without involving human vision. Resolution results for four different spectral band sensors were obtained as well as effective resolution of fused images from some pairs of sensors. Results and the possible use of this synthetic observer resolution approach are discussed.

7689-15, Session 3

Evaluation of hazard and integrity monitor functions for integrated alerting and notification using a sensor simulation framework

M. Uijt de Haag, R. Bezawada, K. Venable, Ohio Univ. (United States)

This paper discusses the results of an initial evaluation study of hazard and integrity monitor functions for use with integrated alerting and notification. The Hazard and Integrity Monitor (HIM) (i) allocates information sources within the Integrated Intelligent Flight Deck (IIFD) to required functionality (like conflict detection and avoidance) and determines required performance of these information sources as part of that function; (ii) monitors or evaluates the required performance of the individual information sources and performs consistency checks among various information sources; (iii) integrates the information to establish tracks of potential hazards that can be used for the conflict probes or conflict prediction for various time horizons including the 10, 5, 3, and <3 minutes used in our scenario; (iv) detects and assesses the class of the hazard and provide possible resolutions. The HIM monitors the operation-dependent performance parameters related to the potential hazards in a manner similar to the Required Navigation Performance (RNP). Various HIM concepts have been implemented and evaluated using a previously developed sensor simulator/synthesizer. Within the simulation framework, various inputs to the IIFD and its subsystems are simulated, synthesized from actual collected data, or played back from actual flight test sensor data. The framework and HIM functions are implemented in Simulink®, a modeling language developed by The

Mathworks . This modeling language allows for test and evaluation of various sensor and communication link configurations as well as the inclusion of feedback from the pilot on the performance of the aircraft.

7689-16, Session 3

ALLFlight: multisensor data fusion for helicopter operations

H. Doehler, T. Lueken, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

After years of experiences regarding enhanced and synthetic vision research projects in the fixed wing domain, the Institute of Flight Guidance is now addressing helicopter applications in the scope of the project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites). The main objective of this project is to demonstrate and evaluate the characteristics of different sensors for helicopter operations within degraded visual environments, such as brownout or whiteout. The sensor suite, which is mounted onto DLR's research helicopter EC135 consists of a standard color TV camera, an un-cooled thermal infrared camera (EVS-1000, Max-Viz, USA), an optical radar scanner (HELLAS-W, EADS, Germany) and a mmW radar system (AI-130, ICx Radar Systems, Canada). The data processing is designed and realized by a sophisticated, high performance sensor co-computer (SCC) cluster architecture, which is installed into the helicopter's experimental electronic cargo bay.

The paper describes applied methods and the software architecture in terms of real time data acquisition, recording, time stamping, and sensor data fusion. Based on replays of recorded sensor information, data fusion techniques are shown in detail. First concepts for a pilot HMI are presented as well.

7689-17, Session 3

Data-driven visibility enhancement using multi-camera system

D. Wu, Q. Dai, Tsinghua Univ. (China)

Poor visibility conditions due to bad weather severely impede applications such as outdoor surveillance and visual navigation for landing or taking off aircrafts. This paper presents a novel method for visibility enhancement in bad weather conditions using multi-camera system. The main contribution lies in the ability to solve ambiguities caused by lack of texture, color and contrast. The ambiguities frequently appear in airport tarmac surveillance and visual navigation, where most existing methods fail.

The proposed method consists of two main components. The first one is a data-driven extraction of template priors matched with currently captured dynamic scene images. A fixed multi-camera system is utilized to record dynamic scene appearances under different capturing conditions, including illuminations, time, seasons and weather for database construction. Then, the database is explored to extract template priors and obtain corresponding scene structures in a data-driven manner. The second one is a dehazing algorithm based on the iteratively optimized dynamic scene depth. Multi-view stereo matching algorithms are employed to calculate the depth information in the foreground object region. The refined depth is obtained by fusing with template depth. Iterations terminate until no further depth refinement. Finally, a physics-based hazy imaging model is utilized to enhance visibility based upon the optimized scene depth.

The proposed method achieves both real-time and robust performances through the combinations of data-driven template prior extraction and dynamic scene depth optimization. Moreover, the estimated weather condition parameters and the real-time reconstructed dynamic scene models are both valuable for other airport surveillance and navigation visualization applications. As far as we know, the proposed method is the first to enhance visibility utilizing multi-camera system. An application based on airport surveillance demonstrates its effectiveness.

7689-18, Poster Session

Spatial awareness using a personal display with relative range and motion estimation

K. L. Bernier, The Boeing Co. (United States)

A person sometimes looses his spatial awareness due to poor visibility or absence of natural illumination. This situation is exemplified by a firefighter who loses awareness of exit paths due to smoke, or a person trapped in total darkness trying to navigate through an unfamiliar room. If not completely occluded by smoke or fog, a flashlight generally provides only a small region of illumination at any one time, requiring the observer to mentally piece together the larger picture through memory and proprioception. This paper presents a method of enhancing spatial awareness by providing a three-dimensional perspective view of a geometry estimation model derived from range measurement and the relative motion between the measurement device and personal display. This estimation model display can provide spatial awareness without the need for direct environment illumination, reducing power and weight requirements, with the ability of covert operation. With a step toward the gaming world, the methods in this paper offer a unique capability for personal entertainment as well.

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7690A-01, Session 1

Current research activities on holographic video displays

L. Onural, F. Yaras, H. Kang, Bilkent Univ. (Turkey)

"True 3D" display technologies target replication of physical volume light distributions. Holography is a promising true-3D technique. Widespread utilization of holographic 3D video displays is hindered by current technological limits; research activities are targeted to overcome such difficulties. Rising interest in 3D video in general, and current developments in holographic 3D video and underlying technologies increase the momentum of research activities in this field. Prototypes and recent satisfactory laboratory results indicate that holographic displays are strong candidates for future 3D displays.

7690A-02, Session 1

Speckle-based phase retrieval applied to 3D microscopy

A. Anand, Maharaja Sayajirao Univ. of Baroda (India); B. Javidi, Univ. of Connecticut (United States)

Nowadays Digital holographic microscopy (DHM) is used for three dimensional imaging of micro-objects. But DHM is a technique which requires the interference between the object beam and a known background, known as the reference beam. The two-beam nature of this makes it prone to external vibrations as well as a tedious adjustment of beam ratios to achieve high fringe contrast. Iterative phase retrieval techniques reconstruct the wavefront from the intensity sampled at several axial planes. This method is an attractive alternative to digital holographic methods, mainly because it is a single beam technique. The wavefront reconstruction is achieved by using the sampled intensity matrices in an appropriate diffraction integral. Angular spectrum propagation approach applied to scalar diffraction theory is used for propagating the wavefront between sampling planes. Here an overview of phase retrieval technique from multiple intensity sampling applied to 3D microscopy is provided.

7690A-03, Session 1

Using disparity in digital holograms for three-dimensional object segmentation

T. Pitkäaho, Univ. of Oulu (Finland); T. J. Naughton, National Univ. of Ireland, Maynooth (Ireland) and Univ. of Oulu (Finland)

Digital holography allows one to sense and reconstruct the amplitude and phase of a wavefront reflected from or transmitted through a real-world three-dimensional (3D) object. However, some combinations of hologram capture setup and 3D object pose problems for the reliable reconstruction of quantitative phase information. In particular, these are cases where the thin image or noise corrupts the reconstructed phase. In such cases it is usual that only amplitude is reconstructed and used as the basis for metrology. A focus criterion is often applied to this reconstructed amplitude to extract depth information from the sensed 3D scene. In this paper we present an alternative technique based on applying conventional stereo computer vision algorithms to amplitude reconstructions. In the technique, two perspectives are reconstructed from a single hologram, and the stereo disparity between the pair is used to infer depth information for different regions in the field of view. Such an approach has inherent simplifications in digital holography as the epipolar geometry is known a priori. We show the effectiveness of the technique using digital holograms of both macroscopic and microscopic real-world objects. We discuss extensions to trinocular and multi-view algorithms, the effect of speckle, sensitivity to the depth of field of reconstructions, and which hologram capture setups are, and which are not, suitable for the technique.

7690A-04, Session 1

Novel proposals in widefield 3D microscopy

G. Saavedra, E. Sanchez-Ortiga, A. Doblas, M. Martinez-Corral, Univ. de València (Spain)

Three-dimensional inspection of microscopic samples is a well established task that relays on the ability of certain microscopes to provide optical sectioning, i.e., capability for obtaining images of different slices of the sample with low cross-talk between them. Although scanning microscopy is widely used for this purpose, faster widefield methods are becoming the preferred choice in the screening of many dynamic phenomena. In this contribution we present novel proposals in two of these techniques, namely, digital holographic and structured illumination microscopy. These new setups increase dra-matically the performance of the conventional instruments, providing the observer with increased flexibilitiy and enhanced adquisition rates.

7690A-05, Session 2

Three-dimensional displays suitable for human visual field characteristics

S. Yano, Advanced Telecommunications Research Institute International (Japan)

We have developed three types of three-dimensional displays, which are considered for the characteristics of human visual field and performance. One display, which is the cubic style, is viewed and operated interactively on the viewer's hand. Viewers surrounding a table view the image of the second display on the tabletop. The third display uses a relatively large screen so several viewers can watch images as conventional large screen displays at the same time. To satisfy the necessary function in these displays, we distribute the use of the horizontal and the vertical disparity to these three displays. First, for the cubic type display, viewers handle it and move it up and down for the interactive communication. We adopted the Integral Photography (IP) display method for this display. Next, for the tabletop type display, we suppose viewers moved only left and right, not up and down, such as the seated position on a chair. This display has just the horizontal disparity, and the display method is one-dimensional IP. The large screen three-dimensional display also uses only the horizontal disparity. Due to the role of this display, an HDTV projector array system is employed for high picture quality.

7690A-06, Session 2

LED projection architectures for stereoscopic and multiview 3D displays

Y. Meuret, L. Bogaert, S. Roelandt, J. Vanderheijden, Vrije Univ. Brussel (Belgium); A. Avci, H. De Smet, Univ. Gent (Belgium); H. Thienpont, Vrije Univ. Brussel (Belgium)

LED-based projection systems have several interesting features: extended color-gamut, long lifetime, robustness, large dimming ratio. The possibility to develop compact projectors however, remains the most important driving force to investigate LED projection. This is related with

the limited luminance of LEDs, compared to high intensity discharge lamps.

We have investigated several LED projection architectures for the development of new 3-D visualization displays.

Polarization-based stereoscopic projection displays are often implemented using two identical projectors with passive polarizers at the output of their projection lens. We have designed and built a prototype of a stereoscopic LCOS projection system that incorporates the functionality of both projectors. An illumination system with LEDs is used. We investigated the possibility to use high-resolution LCOS panels and to add a second LED illumination channel to this optical configuration.

Multiview projection displays allow the visualization of 3-D images for multiple viewers without the need to wear special eyeglasses. Systems with a large number of viewing zones, resulting in high-quality 3-D visualization, have already been demonstrated. Such systems often use multiple projection engines. We have investigated two different projection architectures using only one digital micromirror device and a LED-based illumination system to create multiple viewing zones. These systems are based on time-sequential modulation of the different angular images and special projection screens with micro-optical features. The influence of the limited luminance of LEDs on the possible angular resolution of the 3-D images is analyzed and the potential of laser-based illumination is discussed.

7690A-07, Session 2

Stereoscopic display technologies for FHD 3D LCD TV

D. Kim, Y. Ko, H. Lee, S. Park, J. Jung, D. Hwang, Samsung Electronics Co., Ltd. (Korea, Republic of)

Stereoscopic display technologies have been developed as one of advanced displays, and many TV industrials have been trying commercialization of 3D TV. In 2008, Samsung lauched the world's first 3D TV based on PDP, and has been developing 3D TV based on LCD with LED Back Light Unit (BLU) as more developed one than PDP. However, data scanning driving method and LC's response characteristics of LCD TV cause interference among frames (This is called Crosstalk), and this makes 3D video quality worse. We propose the method to reduce Crosstalk by LCD driving and BLU control of FHD 3D LCD TV.

7690A-08, Session 2

Review of near-eye displays and their applications in 3D visualization

H. Hua, College of Optical Sciences, The Univ. of Arizona (United States)

In this talk, I will review several on-going projects on developing near-eye displays and 3D visualization systems, demonstrate applications of these technologies in 3D visualization, and discuss future directions on near-eye display technologies.

7690A-09, Session 3

Polarization imaging of a 3D object by use of digital holography and its application

T. Nomura, Wakayama Univ. (Japan); B. Javidi, Univ. of Connecticut (United States)

A polarimetric imaging method of a 3D object by use of on-axis phase-shifting digital holography is presented. The polarimetric image results from a combination of two kinds of holographic imaging using orthogonal polarized reference waves. Experimental demonstration of a 3D polarimetric imaging is presented. Pattern recognition by use of

polarimetric phase-shifting digital holography is also presented. Using holography, the amplitude distribution and phase difference distribution between two orthogonal polarizations of 3D phase objects are obtained. This information contains both complex amplitude and polarimetric characteristics of the object, and it can be used for improving the discrimination capability of object recognition. Preliminary experimental results are presented to demonstrate the idea.

7690A-10, Session 3

Focus cues in human visual perception and their realization in 3D displays

S. Reichelt, R. Häussler, G. Fütterer, N. Leister, SeeReal Technologies GmbH (Germany)

In natural viewing situations, depth information is an ever-present cue in the visual perception. Together with other monocular and binocular cues, the focus depth cues contribute subconsciously to our visual ability to perceive the environment in three dimensions. Most of the current approaches to 3D displays utilize the conventional stereoscopic principle. But they all lack of their inherent conflict between vergence and accommodation since scene depth cannot physically realized but only feigned by displaying two views of different perspective on a flat screen and delivering them to the corresponding left and right eye. This mismatch requires the viewer to override the physiologically coupled oculomotor processes of vergence and eye focus which may cause visual discomfort and fatigue. On the other hand, holographic displays deliver full focus cues, and therefore provide the observer with a completely comfortable 3D viewing experience. We have developed and successfully demonstrated a novel approach to real-time display holography based on a sub-hologram encoding technique and a tracked viewing-window technology. Our solution is capable to fulfill the observer's expectations on real depth perception.

This paper discusses the focus cues in the human visual perception for both image quality and visual comfort of 3D displays. Especially we concentrate our analysis on near to medium range depth cues, compare visual performance and depth-range capabilities of stereoscopic and holographic displays, and evaluate potential depth limitations of 3D displays from a physiological point of view. For holographic displays we furthermore examine the effects of hologram synthesis (single/full parallax) on visual perception.

7690A-11, Session 3

High-definition 3D display for enhanced visualization

R. P. Edmondson, J. Vaden, J. F. Morris, B. Hyatt, J. L. Pezzaniti, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); J. L. Tchon, T. J. Barnidge, Rockwell Collins, Inc. (United States)

In this paper, we report on the development of a high definition stereoscopic liquid crystal display for use in a variety of applications. The display technology provides full spatial and temporal resolution on a liquid crystal display panel consisting of 1920x1200 pixels at 60 frames per second. Applications include training, mission rehearsal and planning, and enhanced visualization. Display content can include mixed 2D and 3D data. Source data can be 3D video from cameras, computer generated imagery, or fused data from a variety of sensor modalities. Recent work involving generation of 3D terrain from aerial imagery will be demonstrated. Discussion of the use of this display technology in military and medical industries will be included

7690A-12, Session 4

Exploring cell dynamics at nanoscale with digital holographic microscopy for diagnostic purposes

P. Marquet, Univ. of Lausanne (Switzerland) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); P. Jourdain, Ecole Polytechnique Fédérale de Lausanne (Switzerland); D. Boss, Univ. of Lausanne (Switzerland) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); J. Kühn, Univ. of Lausanne (Switzerland); C. Depeursinge, Ecole Polytechnique Fédérale de Lausanne (Switzerland); P. Magistretti, Univ. of Lausanne (Switzerland) and Ecole Polytechnique Fédérale de Lausanne (Switzerland)

No abstract available

7690A-13, Session 4

Generation, encoding, and presentation of content on holographic displays in real time

E. Zschau, R. Missbach, A. Schwerdtner, H. Stolle, SeeReal Technologies GmbH (Germany)

Classical approaches to generate CGHs (computer generated holograms) are not well suited for interactive applications because of their massive consumption of computing power. So with classical approaches just still images or pre-calculated videos have been implemented. To realize the key benefits of 3D-holography, as compared to 3D-stereo, interactive content is essential - this provides a roadmap for combining typical 3D-applications as professional design, 3D-gaming or 3D-TV with the viewing comfort of 3D-holography. Accordingly, solutions for real-time holographic calculation without the need for high performance computing hardware are required.

This paper discusses our solution for driving holographic displays with interactive or video content encoded in real-time by using SeeReal's Sub-Hologram-technology in combination with off-the-shelf hardware. It includes guidelines for correctly creating complex content and covers aspects regarding transparency in holograms from both the content side and the holography side. Furthermore, the classic approaches for generating CGHs are discussed in comparison with our solution of encoding content using Sub-Holograms which requires only a fraction of the computing power. Finally the computing-platform and the specification of our 20 inch direct-view holographic prototype will be presented.

7690A-14, Session 4

Fourier hologram generation from multiple incoherent defocused images

J. Park, S. Seo, C. Ni, N. Kim, Chungbuk National Univ. (Korea, Republic of)

Hologram is a versatile tool in a wide range of applications. Hologram capturing process, however, requires coherent optics and precise alignment, making it possible only in well-controlled laboratory.

In this report, we propose a method to generate a Fourier hologram of real existing 3D objects without coherent optical system. Instead of setting up an interferometer using laser, one just needs to capture regular incoherent images of the 3D objects at various focal planes. The portion of the object that is located around the focal plane will be focused clearly, while other portions are blurred. The amount of blur is determined by the point spread function of the camera. By sweeping the focal planes, a stack of these depth images of the object space are obtained. In the proposed method, these depth images are summed after they are multiplied by corresponding quadratic phase factors. Then it is normalized by point spread functions of the camera at various depth deviations from the focal plane, resulting in Fourier hologram of the 3D objects.

The proposed method is simple since it does not require complex optical system. Required experimental setup is only a usual camera and incoherent white illumination. 3D structure of the objects does not need to be known. Only point spread functions of the camera are required to be known. Note that the proposed method is different from the methods based on deconvolution of the defocused images in the sense that the proposed method does not extract the depth information of the objects explicitly. In the report, we will explain the principle and present the experimental results for its verification.

7690A-15, Session 4

Wavefront error analysis and compensation in a digital holographic microscope

M. Kim, S. Hong, K. Soh, Seoul National Univ. (Korea, Republic of); S. Shin, Alpha of Professional Person & Technology, Inc. (Korea, Republic of); J. Son, Daegu Univ. (Korea, Republic of); J. Kim, Seoul National Univ. (Korea, Republic of)

The digital holography has a big advantage to retrieve the three-dimensional (3D) information of the object from only one interference recording. Especially, the digital holographic microscope(DHM) using a microscopic objective (MO) has been researched for 3D microscopy. Some papers reported the parametric corrections to compensate the wavefront curvature and the aberrations induced by the MO. While most of small aberrations caused by a MO are compensated through various researches, the measured phase in the optical system, which has the significant wavefront errors in illuminating wave is larger than number of wavelengths, is distorted. Therefore, it is required to illuminate the object by plane wave to obtain the exact 3D information. However, it is difficult to illuminate the object with a plane wave in the case of the reflection imaging because of using a MO. In this paper, a relay lens module which can be adapted to any MOs without significant aberrations is introduced to illuminate the object with a plane wave. The relation between illuminating wave and the measured phase is analyzed based on the wave optics and the analysis is confirmed by the simulations and experiment using the relay lens module. From the result, it is verified that the measured phase is distorted when there exists a significant wavefront errors in illuminating wave, even with an additional task to cancel the phase error. In addition, another method to achieve the exact phase information in spite of the wavefront errors in illuminating wave is derived theoretically and it is demonstrated by the simulation.

7690A-53, Session 4

Fresnel patterns insertion on image for data encoding and robust perceptual image hashing

T. Fournel, A. Rivoire, Univ. Jean Monnet Saint-Etienne (France); J. Becker, Univ. Jean Monnet Saint-Etienne (France) and Ecole Supérieure de Chimie Physique Electronique de Lyon (France)

A piling of Fresnel patterns is inserted in image in order to allow both (associated) data encoding and synchronization for hash value computation [1]. Firstly, Fresnel patterns and their insertion must preserve the perception of the image content and can contribute to visually detect tampering. To encode data, Fresnel patterns can correspond to holograms of basic shapes forming a vocabulary set. The basic shapes consist into distorted versions of a unit disk. The distortions graphically encode the non-cyclic words of a balanced code used in order to preserve a circular shape in average. Data can be automatically decoded by Fresnel reconstruction and morphological processing with Stoka's measure in the space of circles [2].

Secondly, the Fresnel patterns serve as a mesh to be more resistant to geometric distortions [3]. The rings of the Fresnel patterns delimit zones where are applied the iterative filtering algorithm suggested in [4] in order to get an intermediate hash value after randomizing with a secret seed.

In addition to the compact piling, one resulting from a random tiling [5] is also considered as an index usable for checking into a database. The decoding algorithm and the hashing process are tested on face images.

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7690A-16, Session 5

Characteristics of diverging radial type stereoscopic camera

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The currently known stereoscopic camera arrangement methods such as radial and parallel are based on the disparity induced by the distance between left and right cameras. This disparity is diminishing as the camera focus distance increases. For the distance at which the size of the magnified image of a pixel in the image sensor of each camera equals to the camera distance, no disparity will be observed between two camera images. Hence it is difficult to implement these arrangement methods to small imaging devices such as a mobile phone and Hand PC because the focusing distance reduces accordingly as the camera distance becomes smaller. Furthermore, the presentable depth sense will also be reduced because it depends on the disparity between the two cameras. Due to these reasons, the stereo camera mounted on the small imaging devices can only be applicable to a short distance objects and induces very limited depth sense, though the small size image sensor and accordingly small size pixels can somewhat alleviate these problems. In the radially diverging camera arrangement, the camera distance is transformed to the diverging angle of the two camera axes which are crossing to each other at the pivot point. Hence the camera distance can be varied without affecting the diverging angle by simply changing the two camera's distance from the pivot point. This camera arrangement will be good to be mounted on small imaging devices which do not have enough space for a stereo camera.

7690A-17, Session 5

3D imaging system for biometric applications

K. Harding, G. Abramovich, V. Paruchura, S. Manickam, GE Global Research (United States); A. Vemury, U.S. Dept. of Homeland Security (United States)

There is a growing interest in the use of 3D data for many new applications beyond traditional metrology areas. In particular, using 3D data to obtain shape information of both people and objects for applications ranging from identification to game inputs does not require high degrees of calibration or resolutions in the tens of micron range, but does require a means to quicky and robustly collect data in the millimeter range. Systems using methods such as structured light or stereo have seen wide use in measurements, but due to the use of a triangulation angle, and thus the need for a separated second viewpoint, may not be practical for looking at a subject 10 meters away. Even when working close to a subject, such as capturing hands or fingers, the triangulation angle causes occlusions, shadows, and a physically large system that may get in the way. This paper will describe a method to collect medium resolution 3D data, plus high resolution 2D images, using a line of sight approach. The method uses no moving parts and as such is robust to movement (for portability), reliable, and potentially very fast at capturing 3D data. This paper will describe the optical methods considered, variations on these methods, and present experimental data obtained with the approach.

7690A-18, Session 5

High-efficiency acquisition of ray-space using radon transform

K. Yamashita, T. Yendo, M. P. Tehrani, Nagoya Univ. (Japan); T. Fujii, Tokyo Institute of Technology (Japan); M. Tanimoto, Nagoya Univ. (Japan)

In this paper, we propose a method for acquisition of Ray-space from less captured data. Briefly speaking, incomplete data which directly captured by specific device is transformed to full information by information processing.

Ray-space, which represents 3D images, describes position and direction of rays on reference plane in real space. Ray-space has information of many rays. In conventional acquisition of Ray-space, multiple cameras are used and 1 pixel on a camera captures 1 ray. Thus we need many pixels and we must capture the large amount of data.

However Ray-space has redundancy because Ray-space consists of set of lines which depend on depth of objects. We propose method to reconstruct Ray-space acquiring less information with this redundancy. Our method reconstructs Ray-space by 1 pixel capturing several rays and information processing.

We use the Radon transform as information processing. The Radon transform is the integral transform consisting of projection data. The projection data is the integral of a 2D data over straight lines. If we can get projection data, 2D data can be reconstructed calculating the inverse Radon transform of the project data.

Ray-space is a collection of images. A horizontal section image of arranging images is called EPI (Epipolar Plane Image). We can reconstruct Ray-space by acquiring projection data of all EPIs. Acquiring projection data of EPI means capturing sums of brightness value of rays which pass through a point by 1 pixel. Ray-space is reconstructed with less information by acquiring projection data and calculating the inverse Radon transform of the projection data. The sum of brightness value of rays can be acquired by varifocal lens and photodiodes.

We have simulated reconstruction of Ray-space projection data which was computed by computer simulation of proposed device. As a result, using fewer pixels than rays, we could reduce the information to reconstruct Ray-space.

7690A-19, Session 5

All-around convergent view acquisition system using ellipsoidal mirrors

G. Takeda, T. Yendo, M. P. Tehrani, Nagoya Univ. (Japan); T. Fujii, Tokyo Institute of Technology (Japan); M. Tanimoto, Nagoya Univ. (Japan)

In this paper, we propose a new 3D scene acquisition system. The proposed system can capture the dynamic scene from all-around views. When we capture the scene from all-around views, we need to install cameras in circular arrangement. However, it is difficult to install the cameras keeping very narrow intervals in this circular arrangement. Each camera in the arrangement has different parameters like direction and hue.

Therefore, we propose a system. It consists of two ellipsoidal mirrors, a

high-speed camera, and a rotating aslope mirror. As for two ellipsoidal mirrors, the size and the ellipticity are mutually different. The high speed camera is fixed at the top of smaller ellipsoidal mirror to be able to capture the generated images from the aslope mirror. If an object is put at the bottom of the larger ellipsoidal mirror, the rays which are belong to the object reflect the larger ellipsoidal mirror, smaller ellipsoidal mirror, and the aslope mirror respectively and those rays move towards the camera. In this system, it is possible to capture the images of all around view of the object by moving the aslope mirror.

We simulated our system for ray tracing method. In the result, we succeed in acquiring 360 viewpoint images. But, acquired images were distorted. We analyze the distortion distribution to focus rays which is radiated from the camera. We detected that rays traveled toward a direction different from the ideal position.

7690A-20, Session 6

Optical slicing of large scenes by synthetic-aperture integral imaging

M. Martinez-Corral, H. Navarro, G. Saavedra, Univ. de València (Spain); R. Martinez-Cuenca, Univ. de Castellon (Spain); B. Javidi, Univ. of Connecticut (United States)

Integral imaging (InI) technology was created with the aim of providing the binocular observers of monitors, or matrix display devices, with auto-stereoscopic images of 3D scenes. However, along the last few years the inventiveness of researches has allowed to find many other interesting applications of integral imaging. Examples of this are the application of InI in object recognition, the mapping of 3D polarization distributions, or the elimination of occluding signals. One of the most interesting applications of integral imaging is the production of views focused at different depths of the 3D scene. This application is the natural result of the ability of InI to create focal stacks from a single input image. In this contribution we present new setup new algorithm for this optical slicing application, and show that it is possible the 3D reconstruction with improved lateral resolution.

7690A-21, Session 6

Three-dimensional (3D) visualization and recognition using truncated photon counting model and integral imaging

I. Moon, Univ. of Connecticut (United States)

In this paper, a statistical method for three-dimensional (3D) imaging and recognition of events having very small number of photons based on a parametric estimator is overviewed. A truncated Poisson probability density function is assumed for modeling the distribution of small number of photons count observation. For 3D visualization and recognition of photon-limited events, virtual geometrical ray propagation, maximum likelihood estimator (MLE), and statistical inference algorithms are applied to small number of photons counted elemental images set captured by using integral imaging (II). It is shown that the parametric MLE using a truncated Poisson model for estimating the average number of photons for each pixel point of a 3D object has a small estimation error compared with the MLE using a Poisson model. Also, experiments to investigate the effect of 3D sensing parallax on the recognition performance under a fixed mean number of photons is presented.

7690A-22, Session 6

Extension of depth of field using amplitude modulation of the pupil function for bio-imaging

Z. Kavehvash, Sharif Univ. of Technology (Iran, Islamic Republic

of); S. Bagheri, IBM Thomas J. Watson Research Ctr. (United States); K. Mehrany, Sharif Univ. of Technology (Iran, Islamic Republic of); E. Sanchez-Ortiga, M. Martinez-Corral, Univ. de València (Spain); B. Javidi, Univ. of Connecticut (United States)

The depth of focus (DOF) of a light beam is defined as the extent to which the focal spot of light can penetrate along its optical axis without suffering any significant lateral spread. Extended DOF light beams find applications in imaging systems where three dimensional viewing of an object is desired. Here, we present a novel and simple approach for generating extended DOF beams without compromising the lateral resolution. In this method we take advantage of the frequency spectrum of the bio-object. In any given class of bio-objects and given the shape, structure and magnification, the images typically have significant energy in some spatial frequencies. We determine the regions in the spatial frequency domain with such property using PCA method. Then, we design the amplitude modulation function of the pupil plane in a way that MTF of the system will be optimized in those regions for all of the defocus range. In other words we design the pupil function so that the minimum value of MTF in all the defocus values and in regions of interest of spatial frequencies will be maximized. In this way, we have optimized the DOF extension process with blocking the minimum possible area in the pupil domain and for a specific class of bio-objects. This selectively maximizes the output image quality compared to the existing methods where non-optimal blocking of the lens area causes more degradation in output image quality. We show the implantation of this method using an example in bio-imaging.

7690A-23, Session 6

Axially distributed 3D imaging and reconstruction

M. Daneshpanah, R. T. Schulein, B. Javidi, Univ. of Connecticut (United States)

Three-dimensional (3D) imaging systems are being researched extensively for purposes of sensing and visualization in fields as diverse as defense, medical, art, and entertainment. When compared to traditional 2D imaging techniques, 3D imaging offers advantages in ranging, robustness to scene occlusion, and target recognition performance. Amongst the myriad 3D imaging techniques, 3D multi-perspective imaging technologies have received recent attention due to the technologies' relatively low cost, scalability, and passive sensing capabilities.

Multi-perspective 3D imagers collect depth information of the rays by recording 2D intensity information from multiple perspectives, thus retaining both ray intensity and angle information. In this paper, we overview 3D axially distributed sensing architecture and describe associated scene reconstruction algorithms. This imaging system is different comparing to conventional multi-perspective imaging systems in the sense that collection of 3D information is not uniform across the field of view. In particular, since there is no parallax for on-axis objects, no 3D information is recorded. However, the 3D information collection capacity of the sensor increases as objects move to the periphery of the field of view. In addition, similar to other multi-perspective imaging methods, axially distributed configuration offers robustness to object occlusion. However, using a simple back propagation reconstruction technique, maximum occlusion robustness is achieved at the periphery of the field of view. We demonstrate the trend of ray angle gathering capability of this configuration using the maximum angle subtended by the sensor at its initial and final position with respect to the object. The system parameters are analyzed and experimental results are presented.

7690A-24, Session 7

Compressive three-dimensional imaging

A. Ashok, The Univ. of Arizona (United States)

Recognizing the various redundancies inherent in three-dimensional objects we explore the application of various compressive sensing techniques to traditional three-dimensional imaging architectures within a computational imaging framework. We present specific examples of computational imager designs, e.g. 4-D lightfield imager, that employ compressive measurements to infer three-dimensional object information while exploiting both the optical and computational degrees of freedom available to a system designer.

Note: This is an "invited talk."

7690A-25, Session 7

Three-dimensional reconstruction of absorbed data in thin photonic data storage media

O. Matoba, K. Nitta, Kobe Univ. (Japan); W. Watanabe, National Institute of Advanced Industrial Science and Technology (Japan)

We have been investigating a new type of optical data storage media using diffused object. The data is stored as three-dimensional absorbers in a highly scattering media. The scattering media can protect the data. To recover the absorption distribution, scattering coefficient distribution is required. So far, we presented a fabrication method of 3D scattering media by using voids in a transparent material. Voids are fabricated by focused femtosecond laser pulse. In this presentation, we show an algorithm to recover the 3D absorption distribution. Numerical evaluation of the proposed algorithm and storage density are discussed.

7690A-26, Session 7

Geometric analysis on stereoscopic images captured by single high-definition television camera on lunar orbiter Kaguya (SELENE)

M. Miura, J. Arai, J. Yamazaki, H. Sasaki, M. Okui, NHK Science & Technical Research Labs. (Japan); S. Sobue, Japan Aerospace Exploration Agency (Japan); F. Okano, NHK Science & Technical Research Labs. (Japan)

The Japanese lunar orbiter Kaguya (Selenological and Engineering Explorer, SELENE) was launched from the Tanegashima Space Center on September 14, 2007, and the mission was ended on June 11, 2009. A telephoto and wide-angle high-definition television (HDTV) cameras were mounted on the orbiter for publicity, and numerous precious still and moving pictures were captured. In this presentation, we present a method of generating stereoscopic images from the moving pictures captured by one of the HDTV cameras. As objects in the moving pictures look as if they are moving vertically, vertical parallax is caused by time offset of the sequence. The vertical parallax is converted into horizontal parallax by rotating the images by 90 degrees. We generated stereoscopic images from the moving pictures, and confirmed that binocular parallax caused by the method can be dominant for the lunar surface at distance of several hundreds of kilometers. We geometrically analyzed Kaguya's camera configuration for capturing stereoscopic images. We compared the configuration with a general toed-in camera configuration, and revealed that there was axi-asymmetry of camera positions in Kaguya's configuration, which caused a spatial distortion in stereoscopic images. The spatial distortion results from the difference of lateral magnification caused by the camera positions. We also analyzed the spatial distortion geometrically, and compensated the distorted stereoscopic images.

7690A-36, Session 7

Applications of 3D meta-optics for imaging and sensing

E. G. Johnson, P. Srinivasan, M. Poutous, Z. Roth, R. Rumpf, The Univ. of North Carolina at Charlotte (United States)

Diffractive and micro-optics have enabled a large number of applications in imaging, sensing, laser systems, and industrial machining. This is largely due to the development of single step lithography methods that can be easily incorporated into conventional integrated circuit fabrication facilities. As the technology has gained acceptance, novel applications on integrated functionality have driven the requirements from surface relief structures into more complex structures exploiting spatial, spectral, and polarization properties. In order to realize components with these unique aspects, one must concurrently engineer the fabrication process with the desired optical functionality; thereby, enabling one to create engineered 3D Meta-Optics for spatial, spectral, and polarization control. Some of the challenges involve the engineering of optical properties at the sub-wavelength scale with those at the micro-scale. This talk will summarize the design and fabrication issues associated with 3D optics and their potential benefits in passive and active devices for both imaging and sensing.

7690A-27, Session 8

3D display and image processing system for metal Bellows welding

M. Park, Korea Institute of Science and Technology (Korea, Republic of); J. Son, Daegu Univ. (Korea, Republic of)

Industrial welded metal Bellows is in shape of flexible pipeline. The most common form of bellows is as pairs of washer-shaped discs of thin sheet metal stamped from strip stock that normally ranges in thickness from 0.025 to 0.254mm.

Performing laser welding operation may cause dangerous accidents, such as explosion by high temperature or sparks, electric shock, or anoxia and toxic effect by harmful gas and rays. Furthermore, in the process of welding operation, workers have to observe the object directly through microscope adjusting the vertical and horizontal positions of welding rod tip and the bellows fixed on the jig, respectively.

Specifically, to prevent any accidents mentioned above, 3-D display is designed for indirect observation instead of using microscope and stereo images are processed to place rod tip for metal bellows welding.

Main purpose of the system is not only to maximize the efficiency of industrial productivity with accuracy but also to keep the safety standards with the full automation of work by distant remote controlling. Because this pipeline will control the flow of high temperature and high pressure fluids or gas, welding has to be done with very accurate and detailed operation.

7690A-28, Session 8

A best view planning-based 3D full detail textured model reconstruction process through DLT mapping algorithm

C. S. Shih, Tunghai Univ. (Taiwan)

A fast and precise 3D reconstruction process is proposed. It aims to reconstruct a fine detail photo realistic textured digital model of the real world objects.

This process provides a method that applies image feature points matching and alignment of consecutive photos. The taking of photos on real world objects has been planned based on a view planning and view sequencing algorithm. Previous research has suggested that optimizing the view points based on maximum visible edges can lead to minimum

rotation of cameras to acquire complete coverage of the unknown flat surface objects. Also optimizing the view points based on maximum visible triangle faces can lead to minimum rotation of cameras to acquire complete coverage of the unknown curved surface objects. So long as corresponding control points of two photographs align with each other repeatedly, we can offer a coarse model of the original real object as a whole. Once the view sequencing process is complete, we can not only acquire key frames for model reconstruction, but also receive enough information for full detail texture mapping of the digital model.

The whole procedure uses DLT calibration, feature points matching and Delaunay triangulation for model subdivision and fine details 3D model generation. The use of DLT stereo intersection algorithm allows not only stereo model extraction, but also facilitates texture mapping of the object details. In addition to DLT calibration theory, a traditional parallel shift projection geometry method is used for precision comparison.

Experiment results demonstrate that the DLT intersection stereo algorithm is more precise than traditional geometry relation method. When combined with the best view planning and sequencing theory, its role is more valuable than original thought in 3D model digitization of both flat and curved surface objects.

7690A-29, Session 8

Three-dimensional passive millimeter-wave imaging and depth estimation

S. Yeom, D. Lee, J. Son, V. P. Guschin, S. Kim, Daegu Univ. (Korea, Republic of)

In this paper, we address three-dimensional passive millimeter-wave imaging (PMMW) and depth estimation of remote objects. It is well known that passive millimeter wave imaging is robust to poor weather conditions such as fog, smoke, snow, sandstorm, and drizzle as well as night vision. Also, the PMMW imaging detects concealed weapons and hazardous materials due to the capability of penetrating textiles and the high reflectivity on metal and man-made objects. Therefore, depth estimation using PMMW is very useful in harsh outdoor environments. The estimated distance to the concealed object can locate the object in three-dimensional space. We utilize a multi-channel PMMW imaging system, which operates at both 8mm and 3mm regimes with linear polarization. The feature-based PMMW stereo-matching process is proposed to compose three-dimensional maps of near and far objects. The performance is evaluated according to the distance, wavelengths, as well as polarization.

7690A-30, Session 8

Quantum dot dispersions: a new material for true volumetric displays

V. Marinov, I. T. Lima, Jr., North Dakota State Univ. (United States)

The true volumetric displays project a 3D image within a cube viewable from most of its sides, thus providing the ultimate physiological depth cues and critical capabilities for countless applications. The ultra-light and highly transparent aerogels may provide the best optical medium for these displays as they can be easily fabricated in the form of a large volume, low-scattering bulk material. On the other hand, the semiconductor nanocrystals (quantum dots, QDs) are a remarkable fluorescent material with high photostability and other optical properties superior to those of conventional materials. QDs dispersed in aerogels hold a promise to become the most efficient display material for volumetric 3D displays. One important advantage of this material is that it can be scaled up to large and very large 3D display sizes without substantially increasing the cost or performance, incl. luminance. The true volumetric displays described in the literature are built around the concept of two intersecting beams exciting the fluorescent material in their intersection. However, the optical properties of QDs are quite different from these of the fluorescent materials proposed for intersecting-beams displays. It can be argued that it may not be feasible

to build an intersecting-beams volumetric display using QDs. Instead, we are proposing the use of a focused infrared laser beam to excite a unique nanostructured material for volumetric 3D displays consisting of QDs dispersed in a virtually transparent silica aerogel matrix, currently under development at NDSU. We are presenting the theory and experimental results proving the feasibility of this approach.

7690A-31, Session 8

CSI Helsinki: comparing three-dimensional imaging of diagonal cutter toolmarks using confocal microscopy and SWLI

P. Ahvenainen, Univ. of Helsinki (Finland); C. Barbeau, Forensic Technology WAI Inc. (Canada); I. Kassamakov, Helsinki Univ. of Technology (Finland); S. Lehto, T. Reinikainen, National Bureau of Investigation (Finland); E. Hæggström, Univ. of Helsinki (Finland)

This contribution shows that Scanning White Light Interferometry (SWLI) and confocal microscopy can produce consistent high-resolution three-dimensional (3D) images that are relevant for forensic toolmark comparison.

Cutting tools leave characteristic marks that can connect a set of toolmarks to an individual tool. Traditionally forensic experts compare qualitatively two-dimensional (2D) toolmarks using optical comparison microscopes. Crime scene investigators sometimes encounter very small toolmarks which renders 2D comparison insufficient. To address this issue we investigate a 3D comparison method. We cut ten copper wires (2.1±0.1 mm diameter) maintaining a predefined blade orientation and position using a pair of diagonal cutting pliers.

The samples were imaged at three sites employing three techniques: (1) National Bureau of Investigation forensic laboratory in Finland using optical microscopy, (2) Department of physics, University of Helsinki using SWLI and (3) Forensic Technology Inc. facilities in Canada using confocal microscopy. These images were compared to validate the proposed imaging method.

The use of SWLI and confocal microscopy set-ups allows forensic experts to examine surface patterns with sub-micrometer depth precision and allows samples that are too small for 2D techniques to be exploited in forensic work.

7690A-32, Poster Session

Automatic 3D human body shape extraction from a single aperture 3D near-infrared sensor for gender recognition

J. Tang, Alcorn State Univ. (United States)

This paper describes our research on the development of 3-D human body shape extraction technology from a single aperture 3-D near infrared sensor for biometric applications. Firstly, we report our endeavor on the development of a proprietary camera and custom software application package with the capability to provide 3-D human body shape extraction from complex backgrounds. This "3-D Automatic Shape Extraction System", utilizes a single-aperture 3-D sensor which is based on spatial phase technology, to provide an automated process for creating volumetric shape information from captured images of objects and figures. Secondly, we report our research on the applications of 3-D human body shape for gender recognition. Different machine learning algorithms and feature extraction methods are investigated and analyzed in this paper.

7690A-33, Poster Session

Human factor study on the crosstalk of multi-view autostereoscopic displays

J. Yang, K. Huang, C. Wu, K. Lee, Industrial Technology Research Institute (Taiwan); S. Hwang, National Tsing Hua Univ. (Taiwan)

Stereoscopic depth perception has been analyzed in many laboratory experiments since Wheatstone's (1838) discovery that disparity is a sufficient and compelling stimulus for the perception of depth with mirror-type stereo displays. In this paper, mirror-type stereo displays were used as the instrument to provide 3D image in the human factor experiment due to it can provide zero cross-talk 3D images and the images of right and left eye construct 3D image. It can be used to simulate the 9 view 3D display by image processing method with multi-view crosstalk level measured from luminance measurement device. The disparity of multi-view images to form stereopsis with depth perception should be determined first during the content creation and have to be within the fusion limit of human eyes. The experimental design was used for testing subjective evaluations based on the questionnaire, and ANOVA methods were used for analysis. Experimental variables of this human factor study for multi-view 3D display are crosstalk ratios from measured data, with and without shadow effects and three different levels of brightness ratio of foreground object to the background test images. The examination was carried out with a seven-grade subjective evaluation test, that questionnaires provided various indices of depth perception, visual comfort and visual fatigue. Critical Fusion Frequency (CFF) physiological measurement was used in this study for the evaluation of visual fatigue. Results of this research can provide valuable reference to the content makers and for the optimized design of multi-view 3D displays with crosstalk accepted by viewers.

7690A-34, Poster Session

Moiré pattern reduction by using special designed parallax barrier in an autostereoscopic display

W. Yen, C. Wu, C. Wu, C. Tsai, Industrial Technology Research Institute (Taiwan)

More and more autostereoscopic display products adapting lenticular lens or parallax barrier appear in the market. However, moiré effect continues to be an annoying artifact that causes uncomfortable viewing. The moiré pattern is caused by the spatial interference of two regular pattern structures. In the case of an autostereoscopic display, it's caused by the overlap of the lenticular lens or parallax barrier and the pixels of FPD. In order to minimize the moiré effect, we simulate the relationship of moiré strength and various design parameters of the parallax barrier, lenticular lens and black matrix structure of the display panel. According to the simulation results, a combination of multiple parameters was chose to obtain a moiré free autostereoscopic display based on the concept of mutual compensation among the design parameters. After the detailed simulation, experiments of the final design were made to verify the performance of the display.

7690A-35, Poster Session

Comparing numerical error and visual quality in reconstructions from compressed digital holograms

T. M. Lehtimäki, T. Pitkäaho, Univ. of Oulu (Finland); T. J. Naughton, National Univ. of Ireland, Maynooth (Ireland) and Univ. of Oulu (Finland)

Digital holography is a well-known technique for both sensing and displaying real-world three-dimensional objects. Compression of digital holograms has been studied extensively, and the errors introduced by lossy compression are routinely evaluated in a reconstruction domain. Mean-square error predominates in the evaluation of reconstruction quality. However, it is not known how well this metric corresponds to what a viewer would regard as perceived error, nor how consistently it functions across different holograms and different viewers. In this study we evaluate how each of sixteen viewers compared the visual quality of compressed and uncompressed holograms' reconstructions. These responses were plotted against numerical error and compresson ratio. Viewers were asked to determine which of two reconstructions was the compressed one, by which we determined what error level and what compression level corresponded to visually lossles compression. Holograms from five different three-dimensional objects were used in the study, captured using a phase-shift digital holography setup. We applied two different lossy compression techniques to the complex-valued hologram pixels: uniform quantisation, and uniform quantisation of the Fourier coefficients, and used seven different compression levels with each.

7690A-52, Poster Session

Multiple-focus projection technology for near-to-eye applications

E. Buckley, L. Lacoste, J. Freeman, Light Blue Optics Ltd. (United Kingdom)

No abstract available

7690A-54, Poster Session

Novel approach to estimate fringe order in Moire profilometry

M. Kondiparthi, K. R. Lolla, Indian Institute of Science (India)

A novel side illumination based approach capable of assigning fringe order to moiré topography is proposed. Unlike those methods based on fringe projection, where the CCD camera has to resolve shadows of fine grating lines, current proposal does not require a camera with high spatial resolution. Cameras which can resolve low frequency moiré fringes is sufficient. Theory and simulation of the proposed method were dealt in detailed. This analysis is useful not only to assign fringe orders to Moire phase map, but also helps one to extract object surface profile in the presence of surface discontinuities (which will leads to 2π phase jumps).

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7690B-37, Session 9

Panoramic AMLCD display for advanced cockpits

D. C. Huffman, L-3 Display Systems (United States)

The F-35 Joint Strike Fighter (JSF) incorporates the latest technology for aerial warfighting. To support this aircraft's mission and to provide the pilot with the increased situational awareness needed in today's battlespace, a panoramic AMLCD was developed and is being deployed for the first time. This 20" by 8" display is the largest fielded to date in a tactical fighter. Key system innovations had to be employed to allow this technology to function in this demanding environment. Certain older generation aircraft are now considering incorporating a panoramic display to provide their crews with this level of increased capability.

Key design issues that had to be overcome dealt with sunlight readability, vibration resistance, touchscreen operation, and reliability concerns to avoid single-point failures. A completely dual redundant system design had to be employed to ensure that the pilot would always have access to critical mission and flight data.

7690B-38, Session 9

Development of high-performance low-reflection rugged resistive touch-screens for military displays

R. Wang, M. Wang, Advanced Link Photonics, Inc. (United States); J. T. Thomas, General Dynamics Canada Ltd. (Canada); L. Wang, V. Chang, Rayshine Photonics Corp. (Taiwan)

Just as iPhones with sophisticated touch interfaces have revolutionised the human interface for the ubiquitous cell phone, the Military is rapidly adopting touch-screens as a primary interface to their computers and vehicle systems. This paper describes the development of a true military touch interface solution from an existing industrial design. We will report on successful development of 10.4" and 15.4" high performance rugged resistive touch panels using IAD sputter coating. Low reflectance (specular < 1% and diffuse < 0.07%) was achieved with high impact, dust, and chemical resistant surface finishes. These touch panels were qualified over a wide operational temperature range, -51°C to +80°C specifically for military and rugged industrial applications.

7690B-39, Session 9

Cost of ownership for military cargo and tanker aircraft using a common versus disparate display configuration

D. D. Desjardins, Air Force Research Lab. (United States); M. Most, Aeronautical Systems Ctr. Displays Branch (United States)

A 2009 paper considered possibilities for applying a common display suite to various front-line bubble canopy fighters, whereas further research suggests the cost savings, post Milestone C production/deployment, might not be advantageous. The situation for military cargo and tanker aircraft, however, may offer a different paradigm.

The primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price. DODD 5000.01 specifies that all participants in the acquisition system shall recognize the reality of fiscal constraints, viewing cost as an independent variable. DoD Components must therefore plan programs based on realistic projections of the dollars and manpower likely to be available in future years and also identify the total costs of ownership, as well as the major drivers of total ownership costs. In theory, therefore, this has already been done for existing cargo/tanker aircraft programs accommodating independent, disparate display suites. This paper goes beyond that stage by exploring total costs of ownership for a hypothetical common approach to cargo/tanker display avionics, bounded by looking at a limited number of such aircraft, e.g., C-5A, C-17A, C-130H (variants), C-130J, and KC-135. It is the purpose of this paper to reveal whether there are total cost of ownership advantages for a common approach over and above the existing disparate approach. Aside from cost issues, other considerations, i.e., availability and supportability, may also be analyzed.

7690B-51, Session 9

An examination of OLED display application to military equipment

J. T. Thomas, S. Lorimer, General Dynamics Canada Ltd. (Canada)

OLED display technology has developed sufficiently to support small format commercial applications such as cell-phone main display functions. Revenues are sufficient to finance both performance improvements and to develop new applications. This situation signifies the possibility that OLED technology is on the threshold of credible military applications. This paper will examine some possible applications for the military ground mobile environment, identifying the advantages and disadvantages of this promising new technology.

7690B-40, Session 10

Dual redundant display in bubble canopy applications

J. Niemczyk, American Panel Corp. (United States)

Today's cockpit integrator, whether for state of the art military fast jet, or piston powered general aviation, is striving to utilize all available panel space for AMLCD based displays to enhance situational awareness and increase safety. The benefits of a glass cockpit have been well studied and documented. The technology used to create these glass cockpits, however, is driven by commercial AMLCD demand which far outstrips the combined worldwide avionics requirements. In order to satisfy the wide variety of human factors and environmental requirements, large area displays have been developed to maximize the usable display area while also providing necessary redundancy in case of failure. The AMLCD has been optimized for extremely wide viewing angles driven by the flat panel TV market. In some cockpit applications, wide viewing cones are desired. In bubble canopy cockpits, however, narrow viewing cones are desired to reduce canopy reflections. American Panel Corporation has developed AMLCD displays that maximize viewing area, provide redundancy, while also providing a very narrow viewing cone even though commercial AMLCD technology is employed suitable for high performance AMLCD Displays . This paper investigates both the large area display architecture with several available options to solve redundancy as well as beam steering techniques to also limit canopy reflections.

7690B-41, Session 10

Reflectance dependence of displays with circular polarizers

M. Trakalo, General Dynamics Canada Ltd. (Canada)

Display manufacturers go to great lengths to maximize the optical performance of their products. One optical component that has a large effect on display performance is the touch screen. One means of minimizing touch screen reflectance is to include a circular polarizer on the front. The circular polarizer manipulates the state of polarization of the incident light such that the light that is transmitted through the circular polarizer, and subsequently reflected from other optical interfaces, is not transmitted back through the touch screen on its way out, effectively reducing the reflectance of a touch screen. One of the observed characteristics of such a touch screen is that its reflectance depends on its orientation, yielding different reflectance values when the touch screen is in landscape and portrait mode. This paper presents data generated by such reflectance measurements, discusses the underlying cause of this phenomenon and proposes a method of specifying the reflectance.

7690B-42, Session 10

Command and control displays for space vehicle operations

D. D. Desjardins, P. Zetocha, D. Aleva, Air Force Research Lab. (United States)

This paper shall examine several command and control facility display architectures supporting space vehicle operations, to include TacSat 2, TacSat 3, Communications Navigation Outage Forecasting System (CNOFS), and Research Development Test & Evaluation Support Complex (RSC). A principal focus is to provide an understanding for the general design class of displays, currently supporting space vehicle command and control, e.g., custom, commercial-off-the-shelf, or ruggedized commercial-off-the-shelf, and more specifically, what manner of display performance capabilities, e.g., active area, resolution, luminance, contrast ratio, frame/refresh rate, temperature range, shock/vibration, etc., are needed for particular aspects of space vehicle command and control. Another focus shall be to address the types of command and control functions performed for each of these systems, to include how operators interact with the displays, e.g., joystick, trackball, keyboard/mouse, as well as the kinds of information needed or displayed for each function. Comparison with other known command and control facilities, such as Cheyenne Mountain and NORAD Operations Center, shall be made. Future, anticipated display systems shall be discussed.

7690B-43, Session 11

High-definition 3D display for training applications

R. P. Edmondson, J. Vaden, J. F. Morris, B. Hyatt, J. L. Pezzaniti, M. H. Rodgers, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); J. L. Tchon, T. J. Barnidge, Rockwell Collins, Inc. (United States)

In this paper, we report on the development of a high definition stereoscopic liquid crystal display for use in training applications. The display technology provides full spatial and temporal resolution on a liquid crystal display panel consisting of 1920x1200 pixels at 60 frames per second. Display content can include mixed 2D and 3D data. Source data can be 3D video from cameras, computer generated imagery, or fused data from a variety of sensor modalities. Discussion of the use of this display technology in military and medical industries will be included. Examples of use in simulation and training for robot tele-operation, helicopter landing, surgical procedures, and vehicle repair, as well as for DoD mission rehearsal will be presented

7690B-44, Session 11

3D display for enhanced tele-operation and other applications

R. P. Edmondson, J. Vaden, J. F. Morris, B. Hyatt, J. L. Pezzaniti, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); J. L. Tchon, T. J. Barnidge, Rockwell Collins, Inc. (United States); S. Kaufman, QinetiQ North America (United States); D. Kingston, S. Newell, Concurrent Technologies Corp. (United States); B. Pettijohn, A. S. Bodenhamer, U.S. Army Research Lab. (United States)

In this paper, we report on the use of a 3D vision field upgrade kit for TALON robot consisting of a replacement flat panel stereoscopic display, and multiple stereo camera systems. An assessment of the system's use for robotic driving, manipulation, and surveillance operations was conducted. A replacement display, replacement mast camera with zoom, auto-focus, and variable convergence, and a replacement gripper camera with fixed focus and zoom comprise the upgrade kit. The stereo mast camera allows for improved driving and situational awareness as well as scene survey. The stereo gripper camera allows for improved manipulation in typical TALON missions. A test was conducted at Fort Leonard Wood, MO. The upgrade kit, analysis of the test data, and the resulting performance assessment of the 3D vision system are reported. Migration of the technology to enhance other applications such as indirect vision systems for driving, and enhanced security systems are presented.

7690B-45, Session 11

On-demand stereoscopic 3D displays for avionics and military applications

K. R. Sarma, Honeywell Technology (United States)

High speed AM LCD flat panels have been evaluated for use in field sequential mode stereoscopic 3D displays for military and avionics applications. A 120 HZ AM LCD is used in field-sequential mode for constructing eyewear-based as well as autostereoscopic 3D display demonstrators for test and evaluation. The eyewear based system uses shutter glasses to control left-eye/right-eye images. The autostereoscopic system uses a custom backlight to generate illuminating pupils for left and right eyes. It is driven in synchronization with the images on the LCD. Both displays provide 3D effecting in full-color and full-resolution in the AM LCD flat panel. We have realized luminance greater than 200 fL in 3D mode with the autostereoscopic system for sunlight readability. The characterization results and performance attributes of both systems will be described.

7690B-46, Session 12

Wearable computer technology for dismounted applications

R. Daniels, Air Force Research Lab. (United States); P. M. Verret, Ball Aerospace & Technologies Corp. (United States); M. A. Petkosek, Air Force Research Lab. (United States)

Small computing devices which rival the compact size of traditional personal digital assistants (PDA) have recently established a market niche. These computing devices are small enough to be considered unobtrusive for humans to wear. The computing devices are also powerful enough to run full multi-tasking general purpose operating systems. The wearable computer technology market niche is poised to explode with entry of new computing devices that will have to compete with mobile phone technology, mobile phone technology that is beginning to incorporate full multi-tasking operating systems also.

This paper will explore the wearable computer information system for

dismounted applications recently fielded for ground-based US Air Force use. The environments that the information systems are used in will be explained as well as a sample of the connectivity of the net-centric ground based warrior. Unobtrusive operator interfaces will also be discussed.

7690B-47, Session 12

Color tunable photonic bandgap fiber textiles for wearable display applications

M. A. Skorobogatiy, Ecole Polytechnique de Montréal (Canada);
J. Berzowska, Concordia Univ. (Canada)

Integration of optical functionalities such as light emission, processing and collection into flexible woven matrices of fabric have grabbed a lot of attention in the last few years. Photonic textiles frequently involve optical fibers as they can be easily processed together with supporting fabric fibers. This technology finds uses in various fields of application such as interactive clothing, signage, wearable health monitoring sensors and mechanical strain and deformation detectors. As they are designed to minimize signal attenuation and power leakage through cladding, conventional total internal reflection fibers are unsuitable for lateral lighting devices and evolutive appearance accessories. Therefore, light extraction has to be extrinsic, relying on fiber macrobending or cladding post-processing. Recent development in the field of Photonic Band Gap optical fibers (PBG) could potentially lead to novel photonic textiles applications and techniques. Particularly, plastic PBG Bragg fibers fabricated in our group have strong potential in the field of photonic textiles as they offer many advantages over standard silica fibers at the same low cost. Our fibers consist of a solid PMMA core surrounded by the alternating nano-layers of PMMA and PS polymers. The presence of a periodic structure wrapped around the fiber core gives colorful visuals that can be tailored by the fiber geometry design or by active mixing of the reflected and emitted light. Some of the many experimental realization of photonic bandgap fiber textiles and their potential applications in wearable displays will be presented.

7690B-48, Session 12

Visor projected HMD for fast jets using a holographic video projector

J. P. Freeman, P. L. Wisely, BAE Systems plc (United Kingdom); T. D. Wilkinson, Univ. of Cambridge (United Kingdom)

With the advent of faster computers, higher resolution LC displays, and cheap lasers there has been a surge in interest in building video projection systems where a computer generated hologram (CGH) is calculated from the video image and displayed on a LC display (used as a phase device). A laser then reconstructs the video image and projects it. A major advantage of this type of projection system is the LC display can have a substantial number of dead pixels without causing a misinterpretation of the information in the displayed symbology or video. In this work we not only developed an HMD using this technique but also incorporated aberration correction into the hologram to reduce lens complexity and weight. The system was designed to fit onto a conventional HGU53P helmet and project off the slightly forward visor (based on the BAE Systems Viper 1 HMD configuration). The optics, laser and LC display all fitted between the area swept by the raised visor and the helmet shell. The end result was a 22 degree FOV display capable of easily displaying 5000fL symbology at the eye in red or green with a 70% transmissive visor. Symbology and video could be mixed with the symbology an order of magnitude brighter than the video.

7690B-49, Session 12

OLED microdisplay design and materials

I. Wacyk, O. Prache, T. Ali, I. Khayrullin, A. Ghosh, eMagin Corp. (United States)

AMOLED microdisplays from eMagin Corporation are finding growing acceptance within the military display market as a result of their excellent power efficiency, wide operating temperature range, small size and weight, good system flexibility, and ease of use. The latest designs have also demonstrated improved optical performance including better uniformity, contrast, MTF, and color gamut. eMagin's largest format display is currently the SXGA design, which includes features such as a 30-bit wide RGB digital interface, automatic luminance regulation from -45 to +70°C, variable gamma control, and a dynamic range exceeding 50:000 to 1. This paper will highlight the benefits of eMagin's latest microdisplay designs and review the roadmap for next generation devices. The ongoing development of reduced size pixels and larger format displays (up to WUXGA) as well as new OLED materials (e.g. high-brightness yellow) will be discussed. Approaches being explored for improved performance in next generation designs such as low-power serial interfaces, high frame rate operation, and new operational modes for reduction of motion artifacts will also be described. These developments should continue to enhance the appeal of AMOLED microdisplays for a broad spectrum of near-to-the-eye applications such as night vision, simulation and training, situational awareness, augmented reality, medical imaging, and mobile video entertainment and gaming.

7690B-50, Session 12

Near-eye displays for rugged body-worn applications

J. E. Melzer, Rockwell Collins Optronics (United States)

Near-eye displays are finding applications fielded body-worn applications. In these rugged environments, requirements differ from those displays found in aviation or simulation and training applications. This paper will discuss the application-specific requirements for these body-worn applications as well as lessons-learned from the field.

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7691-01, Session 1

Intersatellite radiometric calibration for a satellite radar scatterometer

R. H. Hanna, W. L. Jones, Univ. of Central Florida (United States)

After the launch of NASA's SeaWinds radar scatterometer on the QuikSCAT satellite in 1999, a radiometer function, known as the QuikSCAT Radiometer - QRad, was implemented in the Science Ground Data Processing Systems to allow the measurement of the earth's microwave brightness temperature (Tb) using the radar system noise temperature.

This paper will describe an inter-satellite radiometric calibration technique to validate the QRad brightness temperature algorithm and the QuikSCAT L2A Tb product. This approach allows the inter-comparison of two satellite sensors (radiometers) that have significant differences in their designs. To assess the quality of the QRad instrument, we compare its Tb measurements with the near simultaneous and collocated ocean brightness temperature observations from WindSat on the Coriolis Satellite, which serves as the brightness temperature calibration standard.

Since the QRad and WindSat instruments were of different designs, brightness temperature normalizations were made for WindSat before comparison to account for expected differences in Tb because of incidence angle and channel frequency differences. Brightness temperatures for nine months during 2005 and 2006 were spatially collocated for rain-free homogeneous ocean scenes (match-ups) within 1° latitude x longitude boxes and within a ± 60 minute window. To ensure high quality comparison, these collocations were quality controlled and edited to remove non-homogenous ocean scenes and/or transient environmental conditions, including rain contamination. WindSat and QRad Tb's were averaged within 1° boxes and were used for the radiometric inter-calibration analysis on a monthly basis. Results show that QRad radiometric calibration is stable in the mean over the yearly seasonal cycle.

7691-02, Session 1

Use of environmental impacts in sensor scheduling

P. J. Shea, Black River Systems Co., Inc. (United States); H. E. Snell, M. Gioioso, Atmospheric and Environmental Research, Inc. (United States)

Current surveillance systems operate in a highly dynamic environment in which large numbers of sensors on board multiple platforms must cooperate in order to achieve overall mission success. In an attempt to maximize sensor performance, today's sensors employ rudimentary or, in some cases, inflexible sensor tasking schemes. These approaches are highly tuned to a specific scenario and geometry and are inflexible to changes in the mission, environmental conditions, heterogeneous sensors, and different system architectures. As the complexity of the problem space increases and new sensors become available, it is critical to have a sensor management scheme that is capable of incorporating new environmental knowledge, new sensors and different systems approaches with minimal computational impact on the overall system. Each system should develop an autonomous sensor tasking capability which factors in global concerns within the complete distributed network of platforms and sensors. Moreover, tasking efficiency can be improved by a highly developed understanding of sensor performance at each point in time. This can be achieved by incorporating the impact of problem geometry - sensor location, track object type and view angle - and weather phenomena, such as clouds, aerosols, turbulence and sun glint.

This paper describes our approach for simultaneously optimizing

sensor resource management, surveillance objectives, and atmospheric transmission of signals while minimizing sensor and environmental noise. Our approach uses a genetic algorithm to evolve a population of sensor tasking assignments through constantly-updating track locations, weather conditions, and lighting conditions. Preliminary studies demonstrate encouraging improvements in sensor management performance. We will present results from our preliminary studies and discuss a path forward for our technology.

7691-03, Session 1

A method for studying the effects of thermal deformation on optical system for space application

E. Segato, V. DaDeppo, S. Debei, Univ. degli Studi di Padova (Italy); G. Cremonese, Osservatorio Astronomico di Padova (Italy)

Optical instruments for space missions work in hostile ambient, it's thus necessary to accurately study the effects of ambient parameters variations on the equipment.

In particular optical instruments are very sensitive to ambient conditions, especially temperature. This variable can cause dilatation and misalignment of the optical elements, and can also led to rise of dangerous stresses in the optics. Their displacements degrade the quality of the sampled images.

In this work the optics and mountings of a stereo-camera for the BepiColombo mission are modelled and processed by a thermo-mechanical FEM analysis, reproducing expected operative and flight conditions. The output is elaborated into a MATLAB optimisation code, based on least square algorithm to determine the equation of the best fitting nth polynomial or spherical surfaces of the deformed lenses and mirrors; model accuracy is 10-8m.

The obtained mathematical surface representations are then directly imported into ZEMAX for sequential raytrace analysis. The result is spot diagrams variation due to simulated thermal loads.

This helps also to design and compare different optical housing systems for a feasible solution.

7691-04, Session 1

Zero-G experimental test of a robotics-based inertia identification algorithm

J. J. Bruggemann, M. Kecman, G. Martinez, P. Xie, O. Ma, New Mexico State Univ. (United States)

As satellite on-orbit operations become increasingly aggressive and complex (such as on-orbit refueling, repairing, rescuing, etc.), the need for identifying the inertial properties of spacecraft in orbit is increasing. The importance of this need stems from the fact that spacecraft's advanced control systems require knowledge of the spacecraft's inertia properties. However, the mass and inertia distribution of a spacecraft may change during flight for reasons such as fuel usage, payload deployment or retrieval, etc. The research group has recently proposed a robotics based method of identifying unknown inertial properties of satellites. Previous methods require firing known thrust forces and measuring the resulting velocity and acceleration changes. The new method utilizes the concept of momentum conservation, while employing a robotic device powered by renewable solar energy to change the motion state of the vehicle. Thus, it requires no fuel usage or force and acceleration measurements. The method has been studied using dynamic simulation and analysis. However, its experimental validation is currently an on-going research project. Experimental testing of such a technique prior to use in a real satellite mission is a big challenge

because it requires a full 6-degree-of-freedom motion in zero-gravity conditions. This paper presents efforts to test the inertia identification method using the NASA microgravity aircraft. The paper will describe the design and flight of the test system along with some flight data analysis results. This paper will also introduce the design and development of an air-bearing based test system designed for lab testing of the identification algorithm.

7691-24, Session 2

A scientific revolution: the Hubble and James Webb Space Telescopes

J. P. Gardner, NASA Goddard Space Flight Ctr. (United States)

Astronomy is going through a scientific revolution, responding to a flood of data from the Hubble Space Telescope, other space missions, and large telescopes on the ground. In this talk, I will discuss some of the important discoveries of the last decade, from dwarf planets in the outer Solar System to the mysterious dark energy that overcomes gravity to accelerate the expansion of the Universe. The next decade will be equally bright with the newly refurbished Hubble and the promise of its successor, the James Webb Space Telescope. An infrared-optimized 6.5m space telescope, Webb is designed to find the first galaxies that formed in the early universe and to peer into the dusty gas clouds where stars and planets are born. With MEMS technology, a deployed primary mirror and a tennis-court sized sunshield, the mission presents many technical challenges. I will describe Webb's scientific goals, its design and recent progress in constructing the observatory. Webb is scheduled for launch in 2014.

7691-05, Session 3

SpaceX perspectives on COTS

M. Vozoff, Space Exploration Technologies (United States)

NASA's Commercial Orbital Transportation Services project, or "COTS", has repeatedly been held up as an example of a highly efficient and innovative engagement between the government and commercial enterprise. As such, it represents a model for future programs, offering NASA the opportunity to achieve more within existing budgets while minimizing financial risk to the government and strengthening the domestic aerospace industrial base. Ultimately, this paradigm shows the way forward toward an era in which space exploration is not exclusively funded by tax-payer dollars, but rather a government-commercial partnership in which costs, risks and rewards are more equally shared. This should ultimately sustain a much larger and more robust space industry than is currently possible under government sponsorship.

After three years of development, Space Exploration Technologies (SpaceX) is preparing to complete the final milestones of their COTS agreement including a demonstration mission to deliver cargo to ISS and return some to Earth, immediately followed by operational cargo missions under the Commercial Resupply Services contract (CRS). This paper will describe the distinguishing features and benefits of the COTS paradigm. Lesson-learned from SpaceX's perspective as it approaches completion of this project will be outlined along with observations and experiences. Finally, potential candidates for future COTS-like programs will be identified.

7691-06, Session 3

Commercial orbital transportation system (COTS) project development model: what works and why?

M. J. Horkachuck, NASA Johnson Space Ctr. (United States)

In November 2005, NASA created the Commercial Crew and Cargo

Program Office and Johnson Space Center (JSC) to help usher in a new era in space flight. As part of its authorization, NASA is to implement U.S. Space Exploration policy with investments to stimulate the commercial space industry and facilitate U.S. private industry demonstration of cargo and crew space transport to low earth orbit. Through innovative partnership mechanisms, streamlined project office management and oversight and focused technical assistance and transfer of NASA Lessons Learned since the Apollo program, the COTS program has made tremendous progress with relatively small government budgets. This outlines some of the management techniques used to blend the old way of doing business with the more creative, entrepreneurial methods of commercial companies.

7691-07, Session 4

Performances of AlGaN based focal plane arrays from 10nm to 200nm

J. Reverchon, S. Bansropun, Thales Research & Technology (France); J. Truffer, E. M. Costard, Alcatel-Thales III-V Lab. (France); J. Duboz, J. Brault, E. Frayssinet, Ctr. de Recherche sur l'Hétéro-Epitaxie et ses Appliations (France); A. Giuliani, M. Idir, Synchrotron SOLEIL (France)

The vacuum UV wavelengths (200nm-10nm) are a very difficult range for detection due to the strong interaction of light with materials. Nevertheless, such wavelengths are of prime importance for solar observation. We present several prototypes of focal plane arrays in order to extend the range of detection from near UV to deep UV. All concern 320x256 pixels of Schottky photodiodes with a pitch of 30μm. AlGaN is grown on a silicon substrate instead of sapphire substrate only transparent down to 200nm. After flip-chip hybridization, silicon substrate is thinned and removed by dry etching. The use of honeycomb structure has straightened the membrane after hybridization and allows the membrane integrity. The results show that the dry etching process doesn't affect the readout circuit properties. The dark current is negligible and the measured noise factor is the readout noise due to the large capacitance of the photodiode. We will discuss how to deal with this readout noise of 160 electrons rms by data processing.

The spectral responsivity of this focal plane array presents a quantum efficiency from 10% to 20% from 13nm to 290nm after the removing of the highly doped contact layer. A tradeoff is observed between high quantum efficiency and a high access resistance together with a smearing. We will show how such effects are controlled to be compatible with solar imaging requirements. We studied the effect of distribution of depth etching, honey comb uniformity onto the photoresponse distribution.

7691-08, Session 4

Print and play

K. H. Church, nScrypt, Inc. (United States)

The Air Force has demonstrated an interest in micro-sats which will provide an ability to place multiple small satellites in space with the capability to compete against many of the traditional large satellites that are expensive to launch. In order to do this, it is necessary to decrease the weight and volume without decreasing the capabilities. The Air Force has been working on a concept to enable this and it is coined Cubesat. Cubesat is a "plug and play" approach to sensing and electronics in satellites. The idea will allow any interested parties to make a circuit or sensor that simply and compatibly connects to a micro satellite carrier. This approach will change how satellites are launched and significantly reduce the costs. Our approach is to leverage the Cubesat concept and move from "plug and play" modular approach to "print and play"3D integrated approach. The integration of printed electronics for space is novel since printed electronics is a young technology and geared mainly to consumer applications. The next step to printed electronics is printed 3D electronics. This fabrication process will be a true integration of

mechanical structure and electronic function - the implications for this can be significant in terms of weight and volume savings. Print and play would also ruggedize the micro sat and eventually allow more fuel or batteries to be placed on board, enabling a longer mission.

7691-09, Session 4

The James Webb Space Telescope (JWST)

M. C. Clampin, NASA Goddard Space Flight Ctr. (United States)

The James Webb Space Telescope (JWST) is a large aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments covering the wavelength range of 0.6 μm to 28 μm. JWST's primary science goal is to detect and characterize the first galaxies. It will also study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. JWST is currently in NASA's Phase C/D, with fabrication of the telescope underway. We will present recent progress in hardware development for the observatory, including a discussion of the status of JWST's optical system and fabrication of the beryllium mirrors, recent progress with sunshield development, and plans for the integration and test of the science instruments and the observatory. We also review the expected scientific performance of the observatory in the context of the mission's science requirements.

7691-10, Session 5

Combined differential demodulation schemes for satellite-based AIS with GMSK signals

Z. Zhang, J. Weinfield, J. Shaw, T. Soni, Argon ST, Inc. (United States)

The paper presents a set of new demodulation algorithms for use in satellite systems to receive Automatic Identification System (AIS) signals, with the potential presence of other interfering signals. The combined differential demodulation scheme, referred to as CDD-n, combines n single differential demodulation schemes with appropriately selected weights. Simulation results indicate that the gain under the proposed demodulation scheme is up to 10 dB over several existing non-coherent, single differential demodulation schemes. The impact of the combination coefficients, the number of single differential detectors used, the low pass filter used, the interference and phase shift on the performance are evaluated, respectively. The proposed demodulation schemes are simple and easy to implement in real networks and receivers.

7691-11, Session 5

Co-operative control with intermittent communication

D. Shen, G. Chen, DCM Research Resources, LLC (United States); K. D. Pham, E. P. Blasch, Air Force Research Lab. (United States); J. B. Cruz, Jr., The Ohio State Univ. (United States)

Multiple vehicle decision and control is a subject of great current interest. Tasks, such as cooperative target search, acquisition, and tracking, persistent Intelligence, Surveillance, and Reconnaissance (ISR), persistent area denial, and coordinated attack, can be completed more quickly and efficiently using multiple vehicles, as compared with a single vehicle. Other benefits of multiple vehicle systems include reduced cost by using smaller, cheaper vehicles and increased redundancy for reliability as compared to a single large vehicle. Serious effort has been devoted to the study of cooperative control for these applications, but issues of intermittent communications and limited available information have not been adequately addressed. These issues could arise in persistent area denial, suppression of enemy air defense, combat ISR, urban and "over the hill" reconnaissance, as well as other

surveillance scenarios. Innovative approaches are requested to deal with cooperative control issues arising from intermittent and asynchronous communications, where layered sensing team (e.g. Satellites and UAVs) members' communication is limited. The communicated information could be related to time critical targets, moving targets, pop-up threats or targets, new team member information, or other factors.

In this paper, we extend Nash game based target assignment algorithm proposed by the research team to environments with intermittent asynchronous communication. We propose an Open-Loop Asynchronous Feedback Nash Optimal (OLAFNO) target assignment strategy. The concept of Open-Loop Feedback Optimal (OLFO) is not new. It was originated in the 1970s. The advantages of OLFO are 1) OLFO is simple in concept. Open loop optimization assumes no further feedback beyond the initial identification and estimates the system states and parameters; and 2) OLFO is an adaptive controller using current estimates. With the consideration of limited communications, we improve OLFO using an adaptive Markov-Chain model to estimate the arrival time of the next information update. Here "adaptive" means that our approach can automatically adjust the order of Markov-Chain by doing hypotheses tests based on the past arrival information, as well as adjusting to updated transition probabilities, yielding an adaptive Nash horizon. The open loop Nash optimization is carried out using the predicted update time as the end of the horizon. The strategies are implemented using the asynchronous updates for feedback control. Our proposed OLAFNO is an extended Nash target assignment algorithm with an improved OLFO.

7691-12, Session 5

Two-tier time distribution protocol for deep-space networks

S. S. Woo, J. L. Gao, Jet Propulsion Lab. (United States); D. Mills, Univ. of Delaware (United States)

Time distribution and synchronization in deep space networks are challenging, and may involve operation centers on Earth, multiple orbiters, and landers. Long propagation delays, spacecraft movements, and relativistic effects are fundamentally unique characteristics that deep space networks have to face not only for data communications but also spacecraft time synchronization. Therefore, these aspects hinder the direct application of terrestrial network time protocol (NTP) in deep space environments and require a new paradigm in designing the time distribution and synchronization mechanism.

In this work, we consider the time distribution and synchronization protocol for deep space networks, where Earth functions as a time server and each spacecraft acts as a time client to synchronize to a time server on Earth. We propose a two-tier time synchronization architecture, which is composed of a deep space time distribution component and a proximity time distribution component. We first consider the deep space time distribution protocol to transfer time between Earth and deep space orbiter and then consider the proximity time distribution protocol to transfer time between deep space orbiter and other spacecraft in near planetary. Our approach is more flexible and opportunistic in terms of scheduling, particularly in an environment dominated by link disruption and the lack of contemporaneous end-to-end network paths, compared to the direct end-to-end time distribution and synchronization from Earth to each deep space fleet. The hop by hop time synchronization is maintained in our proposed protocol and benefits of our approach will be addressed.

7691-13, Session 5

Compact time-resolved remote Raman system for detection of hydrous and anhydrous minerals and ices for planetary exploration

S. K. Sharma, A. K. Misra, T. E. Acosta, P. G. Lucey, Univ. of Hawai'i (United States); M. N. Abedin, NASA Langley Research

Ctr. (United States)

Study of minerals, water, carbon and evidence of biomarker has become an important part of NASA's planetary missions in order to search for life on other planets. Water has already been demonstrated on Mars in the form of ice and in hydrous minerals. The University of Hawaii and NASA Langley Research Center are developing small, compact, and portable remote Raman systems with pulsed lasers for planetary explorations under Mars Instrument Development Program. The portable remote Raman instruments previously developed utilized small telescopes with clear aperture of 125 mm and 100 mm diameters have been demonstrated earlier to detect water, ice, and water bearing minerals, carbon in carbonate form in calcite, magnesite, dolomite, siderite, etc. from a distance of 10 to 50 m under daytime and nighttime conditions. Recently, we have significantly reduced the size of our time-resolved (TR) remote Raman system in order to build a compact system suitable for future space missions. This compact time-resolved Raman system has been developed by utilizing (i) a regular 85 mm Nikon (F/1.8) lens with clear aperture of 50 mm as collection optics, and (ii) a miniature Raman spectrograph that is 1/14th in volume in comparison to commercial spectrograph from Kaiser Optical System Inc. used in our previous work. In this paper, we will present the TR remote Raman spectra obtained during daytime from various hydrous and anhydrous minerals, water, water-ice, and CO_2-ice with this new compact remote Raman system to 50 m radial distance with 1 to 10 s of integration time.

7691-25, Session 5

Optical receiver for the ground to space laser time transfer

I. Prochazka, J. Blazej, P. Fort, J. Kodet, Czech Technical Univ. in Prague (Czech Republic)

We are presenting the concept, design and construction of an optical receiver of the space segment for the time transfer ground to space using optical pulses and photon counting detection. Laser time transfer link is under construction for the European Space Agency (ESA) for its application in the experiment Atomic Clock Ensemble in Space (ACES). The device is expected to be launched toward the International Space Station in 2013. The objective of this laser time transfer is the synchronization of the ground based clocks and the clock on board the station with precision of the order of units of picoseconds and the accuracy of 50 picoseconds. The photon counting approach has been selected for on-board optical detection in order to reduce the systematic biases as much as possible. However, the background photon flux of the solar light scattered by the Earth atmosphere and the Earth surface in a wide field of view is a challenge in the optical detector design. The optical receiver concept and the first experiment results of indoor tests are presented.

7691-15, Session 6

Spin-rate control of a spacecraft with flexible booms using H infinity methods

T. Hanis, Czech Technical Univ. in Prague (Czech Republic); R. R. Fullmer, B. Bingham, Utah State Univ. (United States); M. Hromcik, Czech Technical Univ. in Prague (Czech Republic)

Large fluctuations in the Ionospheric electron density can impact communications, surveillance and navigation systems. To study these phenomena, multiple small cubesat-sized spinning spacecraft can make in-situ spatial and temporal measurements using a boom-based Electric Field Probe and a fixed-bias DC Langmuir Probe. Current designs call for four booms ranging from 2 to 5 m in radius from a spacecraft with a mass of under 5 kg.

The design of a spin-rate controller for such a spacecraft has challenges in both the short and long time regions. The short-time region is dominated by the flexible modes of these booms and the uncertainty in

their vibrational modes. The long-term spin rate control of the spacecraft is subject to small eddy current and aerodynamic disturbance torques, with spin-rate time constants in the week range.

A structural finite element mode model of the deployed tape-measure style booms was created. This model was reduced to a linearized lower order model for design purposes using an H∞ fixed order optimization (referred to as HIFOO) control design method. This method provides straightforward frequency based design for systems with multiple mechanical resonances. The robustness of the design was studied by allowing the fundamental eigenvalues drift in frequency and damping values by up to 25 percent. The impact of variable torque authority from the torque coils resulting from orbital variations in the magnetic field was examined. Simulations for both short and long term response demonstrated effective control of the spin rate without inducing extensive boom oscillations.

7691-16, Session 6

The influence of uncertainties of attitude sensors on attitude determination accuracy by linear covariance analysis

J. Blomqvist, R. R. Fullmer, Utah State Univ. (United States)

Picosatellites being considered for future science missions typically require accurate attitude knowledge. The attitude sensors for these spacecraft are often selected from commercial components to reduce costs. Uncertainties in these sensors, along their sensor mounting, the processing methodology, and measurement crosstalk contribute significantly to the accuracy of the attitude solution. This results in questions as to whether the total uncertainty of a specific attitude determination design will meet the mission specifications or if not, what steps in processing, calibration, testing or component replacement need to be made?

The attitude determination accuracy can be estimated based on models of the uncertainties of the sensors and system design. The sensing and estimation process can be approximated as linear with respect to all the small error terms. The linearization of the estimation process as a function of a large number of error sources can be performed automatically using software linearization tools. Propagating these assumed random errors through the estimation provides a total overall uncertainty estimate. Further, the linearized process identifies the major contributors to the overall error, providing guidance to the designer.

A spin-stabilized spacecraft with a two-axis sun sensor and a magnetometer is used as a test example. Nearly one hundred error sources, including sensor mounting, bias drift, sensor noise, thermal fluctuations and cross-talk were examined. As expected, this process identified the few primary contributors to the error. Design actions including improved processing methods, sensor calibration and alignment methods were identified to meet the required system specifications.

7691-17, Session 6

Space target tracking with delayed measurements

H. Chen, Univ. of New Orleans (United States); G. Chen, DCM Research Resources, LLC (United States); E. P. Blasch, K. D. Pham, Air Force Research Lab. (United States)

Tracking space targets from space or from ground measurements typically includes long time delays associated with the communication distance. Representing the tracking as a nonlinear filtering problem, we seek methods for accounting for the delayed measurements which may be in order, or out of order measurements. In a distributed dynamic sensing environment, due to limited communication bandwidth and long distances between the earth and the satellites, it is possible for sensor reports to be delayed when the tracking filter receives them. Such

delays can be complete (the full observation vector is delayed) or partial (part of the observation vector is delayed), and with deterministic or random time lag. We propose an approximate approach to incorporate delayed measurements without reprocessing the old measurements at the tracking filter. We describe the optimal and suboptimal algorithms for filter update with delayed measurements in an orbital trajectory estimation problem without clutter. Then we extend the work to a single target tracking under clutter where probabilistic data association filter (PDAF) is used to replace the recursive linear minimum means square error (LMMSE) filter and delayed measurements with arbitrary lags are be handled without reprocessing the old measurements. Finally, we demonstrate the proposed algorithms in realistic space target tracking scenarios using the NASA General Mission Analysis Tool (GMAT).

7691-18, Session 6

CANARY: ion spectroscopy for situational space awareness

H. S. Feldmesser, M. A. Darrin, R. Osiander, L. J. Paxton, A. Rogers, The Johns Hopkins Univ. Applied Physics Lab. (United States); J. A. Marks, The Johns Hopkins Univ. (United States); M. G. McHarg, R. L. Balthazor, L. H. Krause, U.S. Air Force Academy (United States)

The CANARY Concept is based on the detection of thruster ions and secondary ions and provides a new phenomenology orthogonal to rf and optical detection for 24/7 situational awareness in space which allows to defeat an adversary operating in stealth mode.

The CANARY concept began with the development of a Micro-Electro-Mechanical (MEMS) Flat Plasma Spectrometer (FlaPS), which, integrated with electronics onto FalconSat3 reduced the size of an ion plasma spectrometer to about 10x10x10 cm3 and 250 g. This development, and the follow-on instrument, a Wafer Integrated Spectrometer (WISPER) with 7 different energy/ azimuth ranges created a paradigm shift in the use of such instruments since now allows such an instrument to be used as an additional sensor/payload. The WISPERS Instrument has been both built for USAF Academy Falconsat demonstration. This unit was optimized to map scintillations in the ionosphere. With the capability of detecting ions, the concept of using a highly miniaturized plasma spectrometer was conceived to identify ion thrusters, and on FalconSat 5, the WISPERS instrument is co-positioned with a NRL plasma thruster in the SASSA Experiment. This concept demonstrates the feasibility to detect thrusters. (Hall Effect, Mono methyl hydrazine, Xenon ...)

The goal for this program is to mount a CANARY sensor onto the International Space Station. There are five space vehicles with known arrival and departure time. (Soyez, Shuttles, Progress, ATV, COTS) which leave an ion trail that can be monitored during rendezvous. The WISPERS Instrument will be integrated the to an ExPRESS Logistics Carrier (ELC) which is is an un-pressurized attached payload project for the International Space Station (ISS) that provides mechanical mounting surfaces, electrical power, and command and data handling services for science experiments on the ISS.

7691-19, Session 6

Intelligent sensor tasking analysis for space collision mitigation

S. S. Olivier, A. J. Pertica, Lawrence Livermore National Lab. (United States)

Orbital collisions pose a hazard to space operations as evidenced by the recent destruction of the Iridium 33 satellite due to a collision with the defunct Cosmos 2251 satellite. Although satellites and many large pieces of orbital debris are tracked and have orbital elements published several times per day, conjunction analysis based on this data is often not of sufficient quality to warrant action on the part of satellite operators. Using a high performance computer modeling and simulation

environment for space situational awareness, we explore a new paradigm for improving satellite conjunction analysis by obtaining more precise orbital information only for those objects that pose a collision risk greater than a defined threshold to a specific set of satellites during a specified time interval. In particular, we assess the improvement in the quality of the conjunction analysis that can be achieved using a distributed network of ground-based telescopes along with an intelligent sensor tasking algorithm.

7691-20, Session 6

USAF high-energy laser (HEL) systems: HEL-generated extinction effects and degradation of ATR infrared algorithm efficiencies

C. A. Paiva, BSM Research Associates (United States)

USAF High Energy Laser (HEL) Systems: HEL-Generated Extinction Effects and Degradation of ATR Infrared Algorithm Efficiencies

This research addresses missile exhaust plume ionization as a function of altitude increases, plume expansions, reverse flows and HEL-generated plasmas, as these processes affect multi-wavelength infrared detectors. Boost-phase missile exhaust plumes have been shown to generate a variety of very challenging exhaust-plasma and electromagnetic extinction effects. As a result the HEL fluence (energy in the bucket), and is expected to also decrease in intensity. The overall engagement event results in HEL plasma-plume plasma interactions (absorption-scattering) reducing energy on the infrared focal plane. Specifically such exhaust plasma/HEL/IR interactions generate a reduction of coherence of the detection the target ATDCI (automatic target detection, classification and identification) components and the primary HEL weapon system (USAF Airborne Laser). Missile expanded and reversed exhaust plumes are shown to generate very severe propagation extinction fields within the Prandtl-Meyer and HEL engagement regimes. This further results in inadequate automatic target recognition and pattern reference library efficiencies. Unique plasma-plasma interactions result when assymetric flows interact with high-energy laser transmissions through missile Prandtl-Meyer reverse flow regions and high angle-of-attack regimes. Angle-of-attack asymmetric radiance increases result from increased trajectory energy maintenance maneuvers by boost-phase missiles, and dedicated evasive thrust vectoring. Intense exhaust plume/atmospheric ram interactions result in high critical ionization levels within the missile chemical excitation regions which then interact with HEL designators and primaries. Cumulatively these processes challenge ATDCI algorithms, which rely on ATDCI-ATR (automatic target recognition) referencing systems. Current ATR algorithms do not account for these negative plasma-plasma interactions of assymetric, angle-of-attack rocket exhausts and high-energy laser plasma interactions. ADTCI-ATR libraries must include sufficiently robust exhaust plasma data to insure high probability of successful target intercepts. Finally, these libraries must include angle-of-attack and afterburning characterizations for the new boost-phase Iranian: SHAHAB 5/6, GHADR-110, and North Korean TAEPODONG-2/III ICBM missile systems which are in production.

7691-21, Poster Session

Design and characterization of an optical bandpass filter for the 2009 Mars Science Laboratory mission

T. C. Hale, J. D. Bernardin, J. W. Witt, Los Alamos National Lab. (United States)

The Mars Science Laboratory (MSL) is a NASA sponsored mission of exploration and discovery that will investigate the habitability of the Martian Planet. MSL is a large rover that will carry a suite of ten science instruments to determine if Mars ever was or still is a hospitable place to support life. One of the instruments onboard MSL is ChemCam, a remote sensing instrument that utilizes Laser Induced Breakdown Spectroscopy and high-resolution micro-imaging to determine the

elemental composition and microstructure of rocks and soil. The LIBS portion of ChemCam relies on light-emitting wavelength signatures of vaporized rock and soil material to determine its elemental composition. One of the key subsystems on ChemCam is an Optical Bandpass Filter which segregates the collected light into distinct wavelength bands for measurement and characterization by 3 optical spectrometers (UltraViolet, Visible and Very Near Infrared). This paper describes the optical design, modeling, performance testing and characterization of the Optical Bandpass Filter relative to specified requirements. Conclusions are given concerning the effectiveness of this Optical Bandpass Filter in this light-starved system.

7691-22, Poster Session

Optimize the space combinations of measure vectors of the integrated star-sensor/gyro systems for spacecrafts

X. Li, National Univ. of Defense Technology (China) and China Academy of Space Technology (China); J. Yang, J. Yang, J. Hui, Y. Jiao, National Univ. of Defense Technology (China); M. Yang, D. Wang, Q. Fan, China Academy of Space Technology (China)

In order to achieve continuous attitude information of the spacecrafts or the telescopes, the star-sensors and the gyros are usually integrated to form navigation systems, which measure and determine the attitude-angles synthetically. The star-sensors and the gyros can work properly by determination the attitude-angles from measure-data, and correct each other. In this paper, The space combinations of the measure-vectors of the star-sensors and the gyros are analyzed to find out the influences of the combination modes on the determination precision of the attitude-angles, and the influence trends are summarized. Furthermore, according to the numerical emulation, the optimum space combinations of the measure-vectors are proposed, which can improve the determination precision of the attitude-angles and the redundancy/complement of star-sensors and gyros remarkably. The optimum space combinations of the measure-vectors are benefit for designing optimum integrated star/gyro systems to achieve high determination precision of the attitude-angles, even any of the star-sensors or the gyros works with poor measurement precision, so as to improve the reliability of the navigation systems.

7691-23, Poster Session

Identification of inertia parameters for on-orbit spacecrafts using onboard robotic manipulators

B. Qiao, B. Wan, H. Wu, Nanjing Univ. of Aeronautics and Astronautics (China)

An on-line identification algorithm of inertia parameters for an on-orbit spacecraft based on the active coordinated posture maneuver of two robotic arms is proposed. The main idea of the identification algorithm is to use the active posture maneuver of the two robotic arms mounted on the spacecraft to change the inertia distribution of the spacecraft system. The inertia redistribution will cause a correspondent velocity change of the spacecraft system which can be measured through the onboard velocity sensing system. Considering the fact that the robotic arms of the spacecraft system are precisely modeled, the inertia redistribution of the robotic arms can be computed based on the measureable configuration of the robotic arms. So the only unknown variables in the momentum equations of the spacecraft system are the inertia parameters of the spacecraft body. According to the measured velocity change of the spacecraft system and computed inertia redistribution of the onboard robotic arms, the inertia parameters of the spacecraft body can be identified from the momentum equations of the whole spacecraft system. As two robotic arms are used, the influence of the algorithm on the mission attitude of the spacecraft system caused by the posture maneuver of the robotic arms can be reduced to a minimum level. In

order to verify the proposed algorithm and its sensitivity to measurement noise, computer simulations are conducted.

7692-15, Session 1

All weather collision avoidance for unmanned aircraft systems

M. R. Contarino, Scire Consultants LLC (United States)

For decades, military and other national security agencies have been denied unfettered access to the National Air Space (NAS) because they lack a highly reliable and effective collision avoidance capability. The controlling agency, the Federal Aviation Administration, justifiably demands "no harm" to the safety of the NAS.

To overcome the constraints imposed on Unmanned Aircraft Systems (UAS) use of the NAS, a new, complex, conformable collision avoidance system has been developed - one that will be effective in all flyable weather conditions, overcoming the shortfalls of other sensing systems, including radar, lidar, acoustic, EO/IR, etc., while meeting form factor and cost criteria suitable for Tier II UAS operations. The system also targets Tier I as an ultimate goal, understanding the operational limitations of the smallest UASs may require modification of the design that is suitable for Tier II and higher.

The All Weather Sense and Avoid System (AWSAS), takes into account the FAA's plan to incorporate ADS-B (out) for all aircraft by 2020; and it is intended to make collision avoidance capability available for UAS entry into the NAS as early as 2013. When approved, UASs can fly mission or training flights without constrained access to the NAS presently in place.

When implemented this system will achieve collision avoidance capability for UASs deployed for national security purposes and will allow expansion of UAS usage for commercial or other civil purposes.

7692-03, Session 2

Human robot interaction research for current and future military applications: from the laboratory to the field

K. A. Cosenzo, M. J. Barnes, U.S. Army Research Lab. (United States)

Unmanned air and ground vehicles (i.e., robots) are an integral part of current and future military operations. The use of the robot goes beyond moving the platform from point A to point B. The operator who is responsible for the robots will have a multitude of tasks to complete; route planning for the robot, monitoring the robot during the mission, monitoring and interpreting the sensor information received by the robot, and communicating that information with others. As a result, the addition of robotics can be considered a burden on the operator if not integrated appropriately into the system. The goal of the US Army Research Laboratory's Human Robotic Interaction (HRI) Program is to enable the Soldier to use robotic systems in a way that increases performance, that is, to facilitate effective collaboration between unmanned systems and the Soldier. The HRI program uses multiple research approaches: modeling, simulation, laboratory experimentation, and field experimentation to achieve this overall goal. We have basic and applied research in HRI to include cognitive robotics, supervisory control, mounted and dismounted robotic control, and mitigation strategies for the HRI environment. In addition we support both current applications of robotics systems by applying our human factors expertise to the system design. This paper will describe our HRI program across these various domains and how our research is supporting both current and future military operations.

7692-04, Session 2

Robust natural language dialogues for instruction tasks

M. Scheutz, Indiana Univ. (United States)

Being able to understand and carry out spoken natural instructions even in limited domains is extremely challenging for current robots. The difficulties are multifarious, ranging from problems with speech recognizers, to difficulties connected to parsing disfluent speech or resolving references based on perceptual or task-based knowledge. In this talk, we are starting to address the above problems with an integrated natural language understanding system on a robot that can handle fairly unconstrained spoken ungrammatical and incomplete instructions reliable in a limited domain.

7692-05, Session 2

Field testing of tele-operation versus shared and traded control for military assets: an evaluation involving real-time embedded simulation and soldier assessment

J. S. Metcalfe, DCS Corp. (United States); J. Alban, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States); K. A. Cosenzo, U.S. Army Research Lab. (United States); T. G. Johnson, E. Capstick, DCS Corp. (United States)

With the broader robotics community, those applying autonomous technologies to future military systems strive to enhance human (Soldier)-robot and robot-robot performance. Beyond performance, the military must be concerned with Local Area Security; characterized as "Secure Mobility", military systems must enable safe and effective terrain traversal concurrent with maintenance of Situational Awareness (SA). One approach to interleaving these objectives is supervisory control, with popular options being shared and/or traded control schemes. Yet, with the scale and expense of military assets, common technical issues such as system lag, transition time, and safeguarding become critical; especially as they interact with Soldier's capabilities. Thus considerable study is required to enable selection and implementation of control methods that optimize Soldier-system performance while safeguarding both individually. The current report describes a field experiment of such control schemes utilizing a combination of real experimental military vehicles and enhanced simulation and visualization systems enabling teleoperation and supervisory control as well as SA monitoring and reporting. Automated triggering of military-relevant SA demands (audio commands) were interspersed with a set of pre-planned driving maneuvers in a 'teleoperation-like' context (control from within a moving vehicle) to examine the influence of supervisory control technologies on Soldier-system performance in a realistic operational context. Results indicated that direct application of supervisory control methods, while beneficial under particular demands, require continued development to be perceived by Soldiers as useful and reliable. Future efforts should more tightly couple the information exchanged between the Soldier and system to overcome current challenges not addressed by standard control methods.

7692-06, Session 2

Comparison of tele-operation and supervisory control for navigation and driving under reduced bandwidth

S. T. Hunt, G. Witus, Turing Associates, Inc. (United States); R. D.

Ellis, A. K. Pandya, Wayne State Univ. (United States)

Distance, line-of-sight obstructions, other radio emitters, multi-path transmission and other factors reduce communications bandwidth. Video transmission with reduced bandwidth requires tradeoff among temporal, spatial and color/luminance resolution. This paper presents interim results of a study comparing teleoperation and semi-autonomous supervisory control as a function of available bandwidth. In teleoperation, the operator exercises synchronous, continuous, real-time control of the UGV translation and rotation rates. In supervisory control, the operator intermittently designates a goal point which the UGV attempts to home in on automatically using on-board perception and processing. The optimal allocation of bandwidth for teleoperation might not be the same for as for supervisory control, since the operator's task is different. We conducted tests to determine the relative performance impact of reducing frame rate, image resolution and color/luminance resolution for given available bandwidth, under teleoperation and supervisory control. Performance was measured by time and accuracy in a simplified, repeatable driving and navigation task. We then compared teleoperation performance under the best conditions for teleoperation to supervisory control performance under the best conditions for supervisory control, for the same bandwidth.

7692-07, Session 2

Combined virtual and real robotic test-bed for single-operator control of multiple robots executing cooperative algorithms for contaminant localization

S. Y. S. Lee, S. T. Hunt, A. Cao, A. K. Pandya, Wayne State Univ. (United States)

Studies of multi-robotic systems are expensive due to the need of robotic agents. In order to make these systems more cost effective, flexible and rapidly configurable, a test-bed combining both virtual and real robotic has been developed. This test-bed environment is developed for experiment, development, and control of multi-robot systems. Teams of robots can complete tasks such as multipoint surveillance, cooperative transport, and explorations in hazardous environments. But can groups of robots perform tasks more efficiently and robustly than a single robot? In applications of odor sniffing robots that are time-critical such as search and detection operations or safety and control operations at airports, hazards need to be found as fast as possible. Does using groups of robots have advantages of allowing more contaminant sources to be pursued simultaneously? Can multiple robots be controlled by a single operator? What are the performances vs. effectiveness tradeoffs? This paper will address some of these fundamental questions in human-multi-robot interactions within the framework of our virtual/ real test-bed. In addition, cooperative control algorithms are developed for contaminant localization and will be implemented on teams of heterogeneous real and virtual robots.

7692-08, Session 2

Experimentation and evaluation of threat detection and local area awareness using advanced computational technologies in a simulated military environment

J. A. Davis, Jr., G. Brick Larkin, U.S. Army Research Lab. (United States); T. G. Johnson, J. S. Metcalfe, DCS Corp. (United States); K. S. Oie, U.S. Army Research Lab. (United States); V. Paul, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States)

Tomorrows military systems will increasingly exploit advances in intelligent computation and visualization to enhance Local Area Awareness (LAA) to achieve safety and Situational Awareness (SA) in

operations involving vehicle and Soldier mobility in mixed-initiative systems. Although integrated intelligent automation may augment Soldier capabilities and enable supervisory control of multiple assets, it may also reduce Soldier-system performance as a function of demand on workload resources; requiring concurrent human performance evaluation with system design. The present paper describes an approach to systems engineering that supports testing and evaluation in environments closely approximating the operational context within which such future systems are to be deployed. A distributed system comprised of several complex elements was required to emulate the appropriate technical and operational environment. Separate computational and visualization systems provided an environment that was representative of the current theater of operations, including a 3D urban environment complete with dynamic human entities of various types (Soldier, civilian, insurgent). Semi-autonomous driving was achieved using blind route following with a simulated autonomous mobility system and LAA was probed through digital SA reports with a real military crewstation mounted on a 6-DOF vehicle motion simulator. Soldier cognitive state evaluation was enabled using physiological monitoring. Analyses indicated differential temporal and accuracy components associated with identifying key features of potential threats; i.e., comparing Soldiers and insurgents with non-insurgent civilians. Clearly, the chosen approach provided a natural and operationally-relevant means of assessing needs of designing future secure mobility systems and detecting key factors affecting Soldier-system performance as foci for future development.

7692-10, Session 2

Human-robot interaction modeling and simulation of supervisory control and situational awareness during field experimentation with military manned and unmanned ground vehicles

T. G. Johnson, J. S. Metcalfe, B. Brewster, C. Manteuffel, M. Jaswa, DCS Corp. (United States); T. M. Tierney, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States)

The proliferation of intelligent systems in today's military demands increased focus on the optimization of human-robot interactions. Traditional studies in this domain involve large-scale field tests that require humans to operate semi-automated systems under varying conditions within military-relevant scenarios. While this method provides an effective means of answering particular empirical questions, it is intrinsically limited by human, technical, and fiscal resources. Provided that adequate constraints are employed, modeling and simulation can be a cost-effective alternative and supplement. Indeed, the development of representative computational architectures for such complex systems is a nontrivial task. The current presentation discusses one such effort. Herein, a simulation effort is described that was constructed and executed in parallel with a field test with actual Soldiers operating real military vehicles in an environment that represented key elements of the true operational context. In this study, "constructive" human operators were designed to represent the performance of average Soldiers executing supervisory control over an intelligent ground system. The constructive Soldiers were simulated performing the same tasks as those performed by real Soldiers during a directly analogous field test. Exercising the models in a high-fidelity virtual environment provided predictive results that represented actual performance in certain aspects, such as situational awareness, but diverged in others. These findings largely reflected the quality of modeling assumptions used to design elemental behaviors and the quality of information available on which to articulate principles of operation. Ultimately, predictive analyses partially supported expectations, with deficiencies explicable via Soldier surveys, experimenter observations, and previously-identified knowledge gaps.

7692-11, Session 2

Delegation control of multiple unmanned systems

S. R. Flaherty, R. J. Shively, U.S. Army Aeroflightdynamics Directorate (United States)

Maturing technologies and complex payloads coupled with a future objective to reduce the logistics burden of current UAS operations require a change to the 2-crew employment paradigm for unmanned systems. Increased automation and operator supervisory control of unmanned systems have been advocated to meet the objective of reducing the logistics burden, while managing future technologies. Specifically, a playbook employment strategy or Delegation Control has resulted in reduced workload and higher situation awareness with increased mission performance for single operators controlling multiple unmanned systems in empirical studies (Parasuraman et al., 2005; Fern & Shively, 2009). Delegation control is characterized as a UAS employment strategy where an operator can call a single "play" that initiates prescribed default actions for each vehicle and associated sensor related to a common mission goal. Based upon the effectiveness of delegation control in simulation, the U.S. Army Aeroflightdynamics Directorate (AFDD) developed a Delegation Control operator interface with voice recognition implementation, for play selection, real-time play modification, and play display status with automation transparency to enable single operator management of multiple air and ground unmanned systems in flight. AFDD successfully demonstrated delegation control in a Troops-in-Contact mission scenario at Ft. Ord in 2009. The demonstration featured a simultaneous collaborative virtual UAS weapons engagement and coordinated live UAV-UGV slingload drop by a single operator. This summary substantiates implementation of delegation control in flight and provides justification for further development and testing of robust, flexible play definitions as a beneficial advance in single operator control of multiple unmanned vehicles.

7692-01, Session 3

Close range ISR (PRISTA) and close quarters combat (CQC) with unmanned aerial systems (UAS)

J. R. Maynell, Jr., Lite Machines Corp. (United States)

Ironically, the final frontiers for the UAV are the closest spaces at hand. There is an urgent operational capability gap in the area of proximate reconnaissance, intelligence, surveillance, and target acquisition (PRISTA) as well as close quarters combat (CQC). Needs for extremely close range functionality in land, sea and urban theaters remain unfilled, largely due to the challenges presented by the maneuverability and silent operating floor required to address these missions. The evolution of small, nimble and inexpensive VTOL UAV assets hold much promise in terms of filling this need.

An autonomous UAV, if small, light and inexpensive enough, could serve as a true organic companion system for each individual dismount. Since a PRISTA/CQC capable VTOL UAV would be the only type of unmanned asset that can go anywhere troops can go, it has the potential to take over PRISTA/CQC tasks presently performed by ground-based troops. This type of troop replacement system would forever change the way many hazardous ground-based missions are performed, providing enormous life-saving benefits to troops deployed in any mission setting.

7692-12, Session 3

Stereo vision-based perception capabilities developed during the robotics collaborative technology alliances program

A. L. Rankin, M. Bajracharya, A. B. Howard, L. H. Matthies, B. Moghaddam, A. Huertas, A. I. Ansar, Jet Propulsion Lab. (United States)

The Robotics Collaborative Technology Alliances (RCTA) program, which ran from 2000 to 2009, was funded by the U.S. Army Research Laboratory and managed by General Dynamics Robotic Systems. The Alliance brought together a team of government, industrial, and academic institutions to address research and development required to enable the deployment of future military unmanned ground vehicle systems ranging in size from man-portables to ground combat vehicles. Under RCTA, three technology areas critical to the development of future autonomous unmanned systems were addressed: advanced perception, intelligent control architectures, and human-robot interaction. The Jet Propulsion Laboratory (JPL) participated as a full member for the entire program, working three tasks in the advanced perception technology area: stereo-vision algorithm enhancements, terrain classification, and pedestrian detection in dynamic environments. Under the stereo-vision enhancements task, significant improvements were made to the quality of range data at object boundaries. Under the terrain classification task, a multi-cue water detector was developed that fuses cues from color, texture, and stereo range data, and a multi-sensor mud detector was developed that fuses cues from color stereo and polarization sensors. In addition, a stereo-vision based long-range terrain classifier was implemented that uses self-supervised learning of traversability to extend the classification of terrain over which the vehicle drives to the far-field. Under the pedestrian detection task, stereo vision was used to identify regions-of-interest in an image, classify those regions based on shape, and track detected pedestrians in three-dimensional world coordinates. This paper summarizes JPL's stereo-vision based perception contributions to the RCTA program.

7692-13, Session 3

Real-time 3D data gathering, visualization, and data fusion from manned/unmanned platforms

J. A. Alberts, Autonomous Solutions, Inc. (United States)

With funding from NAVEODTECHDIV, ARDEC, TARDEC, and SPAWAR, Autonomous Solutions has developed and continues to develop a real time 3D world building application that creates fast 3D models and rendering of target locations for use in robotic control tasks, object identification, situational awareness, and remote object measurement. To correct for errors in the positioning system, point cloud registration algorithms are used to stitch world models as the user drives the platform through the environment. Thus, 3D worlds can be built and displayed in real time as a user, vehicle, or robot, moves through an environment. These worlds can be viewed from any perspective by multiple users. This data can be geo-registered such that it can be overlaid with existing a priori data to give a constantly updated map. The data can also be stored in a database and used for post-mission forensic analysis and change detection. The stitched models complement large aerial terrain data by providing a higher detail ground based representation of a target. The repository of 3D data can also be accessed for machine automation systems for planning and perception tasks such as recognizing objects, such as doors and stairs, and creating traversable paths through them. This system is also scalable for use with a team of robots, such that collaboration could more efficiently create decentralized 3D databases of a large target area.

7692-14, Session 3

Velodyne HDL-64E lidar for unmanned surface vehicle obstacle detection

R. Halterman, M. H. Bruch, Space and Naval Warfare Systems Ctr. Pacific (United States)

The Velodyne HDL-64E is a 64 laser 3D (360x26.8 degree) scanning

LIDAR. This paper presents the performance of the HDL-64E as it relates to the marine environment for unmanned surface vehicle (USV) obstacle detection and avoidance. We describe the sensor's capacity for discerning relevant objects at sea-both through subjective observations of the raw data and through rudimentary automated obstacle detection algorithms. The HDL-64E was designed to fill perception needs of DARPA Urban Challenge vehicles. As such, it was principally intended for ground use. SPAWAR Systems Center, Pacific was the first organization to extensively experiment with the sensor's capabilities for obstacle detection and avoidance aboard an autonomous USV.

Obstacle detection in a marine environment entails a number of challenges and simplifications compared with the urban environment. Specifically, the surface is often specularly reflective and non-flat, and the obstacle distribution is frequently sparse or disorganized. The HDL-64E generally sees no return from an unchurned ocean surface. It is sensitive to small objects such as kayaks and logs at approximately 30-50 meters and to ships at 100-120 meters. Through a number of tests in both open and protected water, we find that the HDL-64E fills a niche of high refresh rate and resolution, medium range sensing and complements lower rate and resolution, longer range marine RADARs.

7692-16, Session 3

A real-time pedestrian detection system based on structure and appearance classification

M. Bansal, S. Jung, B. C. Matei, J. Eledath, H. S. Sawhney, Sarnoff Corp. (United States)

We present a real-time pedestrian detection system for autonomous and semi-autonomous unmanned vehicle systems based on structure and appearance classification. We discuss several novel ideas that contribute to having low-false alarms and high detection rates, while at the same time achieving the computational efficiency needed for deployment in the field: (i) At the front end of our system we employ stereo to detect pedestrians in 3D range maps using template matching with a representative 3D shape model, and to classify other background objects in the scene such as buildings, trees and poles. The structure classification efficiently labels substantial amount of non-relevant image regions and guides the further computationally expensive process to focus on relatively small image parts. The obtained image labeling is also appropriate for robotic vehicles on exploratory missions in unknown environments; (ii) We improve the appearance-based classifiers based on HoG descriptors by performing template matching with 2D human shape contour fragments that results in improved localization and accuracy; (iii) We build a suite of classifiers tuned to specific distance ranges for optimized system performance. Our method is evaluated on publicly available datasets and is shown to match or exceed the performance of leading pedestrian detectors in terms of accuracy as well as achieving real-time computation (10 Hz), which makes it adequate for field robotic deployment.

7692-17, Session 3

ESARR: enhanced situational awareness via road sign recognition

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Situational Awareness (SA) systems leveraging Global Positioning Systems (GPS) and Geographical Information Systems (GIS) have become a mainstay for vehicles, troops, and even unmanned systems (such as unmanned ground vehicles (UGVs)). Unfortunately, in urban, semi-urban or canopied terrain GPS signals can be difficult or impossible to receive consistently. New and alternative tools to enhance situational

awareness are needed to fill this gap. Road signs, particularly directional road signs, containing street names, place names, distances, etc. can potentially serve as an alternative to GPS in these environments - by definition, they are designed to provide information related to location. The authors have begun development of ESARR: a tool for enhanced situational awareness via road sign recognition. When complete, the system will provide enhanced SA to both manned and unmanned systems by (a) detecting and interpreting all types of road signs relevant to SA, (b) relating the extracted information to maps/GIS to ascertain position (i.e. geo-bounding), and (c) efficiently communicating this information back either a human user or navigation algorithm in a manner that is timely and informative.

In this paper, ESARR development progress will be reported on, including the design and architecture, image processing framework, geobounding methodologies, and results to date. Highlights of the real-time vehicle-based road-sign reading system will be described along with the challenges and progress in overcoming them.

7692-18, Session 3

A final evaluation of pedestrian detection and tracking from a moving platform

B. A. Bodt, R. Camden, U.S. Army Research Lab. (United States)

This work represents the fifth in a series of studies on safe operations of unmanned ground vehicles in the proximity of pedestrians. The U.S. Army Research Laboratory (ARL), the National Institute of Standards and Technology (NIST), and the Robotics Collaborative Technology Alliance (RCTA) conducted the study on the campus of NIST in Gaithersburg, MD in, 2009, the final year of the RCTA.

The experiment was to assess the performance of six RCTA algorithms to detect and track moving pedestrians from sensors mounted on a moving platform. Sensors include 2-D and 3-D LADAR, 2-D SICK, and stereovision. Algorithms reported only detected human tracks. NIST ground truth methodology was used to assess the algorithm-reported detections as to true positive, misclassification, or false positive as well as distance to first detection and elapsed tracking time. A NIST-developed viewer facilitated real-time data checking and subsequent analysis. Factors of the study include platform speed, pedestrian speed, and clutter density in the environment. Pedestrian motion was choreographed to ensure similar perspective from the platform regardless of experimental conditions. Pedestrians were upright in the principal study, but excursions examined group movement, nonlinear paths, occluded paths, and alternative postures.

The presentation will present the findings of this study and benchmark detection and tracking for subsequent robotic research in this program. We will also extend the analysis to discuss pedestrian avoidance based on information from a collection of fused algorithms.

7692-19, Session 3

Vision systems for manned and robotic ground vehicles

J. N. Sanders-Reed, Boeing-SVS, Inc. (United States); P. L. Koon, The Boeing Co. (United States)

Boeing has developed and demonstrated distributed aperture vision systems for a variety of manned and unmanned ground vehicle applications. The current work builds on over 10 years of distributed aperture Enhanced and Synthetic Vision Systems (ESVS) development for airborne applications. Over the past 2 years this work has been applied to closed hatch drive by wire, wireless remote tele-operation, and wireless remote supervised autonomy operation of various ground vehicles. This paper describes the application of distributed aperture vision systems to these ground vehicle applications.

The distributed aperture Enhanced Vision System (EVS) provides 360 degree vision displayed on either flat panel displays or head mounted displays (helmet or VR goggles). Multiple visible and infra-red (IR)

cameras are used to provide high resolution, day/night capability. The system described is a modular, scalable system which allows easy tailoring to trade-off cost versus performance. In addition, the use of a distributed aperture system allows multiple crew members to simultaneously look in different directions.

The primary test bed vehicle for these demonstrations was a drive by wire Chevrolet Tahoe, although other vehicles were also utilized. For the demonstration systems, the cameras were mounted in a roof mounted temperature controlled sensor pod. For many end use systems, the sensors would instead be physically distributed around the vehicle (Boeing operates a separate Mobile Test Van with spatially distributed sensors to explore issues arising from spatial separation). The processing system is a very low latency (16 ms processing) FPGA processor which performs image stitching between common modality sensors and image fusion between visible and IR sensors. The processor also allows the user to electronically zoom the Field Of View (FOV). The user's Line Of Sight (LOS) is tracked using an optical head tracker. The LOS data is input to the FPGA processor which assembles the appropriate display image, stitching and blending sensors as appropriate, to match the instantaneous LOS and FOV. The resulting imagery is then compressed using a low latency JPEG compression and sent over a wireless link to a remote user where the video stream is decompressed and displayed, along with vehicle status information.

The initial demonstration was a tele-operation using a simple sensor pod consisting of 3 grey scale visible band cameras providing 180 degree FOV in the forward direction. The remote driver, located in a separate chase vehicle up to ½ mile distant drove the Tahoe using the wireless video displayed on VR goggles and on a flat panel display. Following this initial demonstration, the sensor suite was upgraded to 6 HDTV (1920x1080 pixel) color cameras providing 360 degree FOV plus 3 640x480 LWIR cameras providing 180 degree FOV in the forward direction. For the next demonstration, the Tahoe operated in an autonomous operations mode, using GPS way-points to follow a pre-planned route. The video was used to perform automatic perimeter surveillance. A base station automatically sent FOV pointing commands to the vehicle to pan the LOS through the 360 degree FOV or simply back and forth. The base station recorded the resulting video, sent over a wireless mesh radio network and processed it to perform intruder detection. The upgraded sensor pod was also used to perform "closed hatch" operations. For these, the operator was actually located in the Tahoe but sitting in an enclosed space in the rear seat (no external view). The vehicle was driven using both VR Goggles and flat panel display. It was observed that the learning curve to drive the vehicle off the flat panel display was much easier than driving off the VR goggles, but situational awareness with the VR goggles was much greater than with the flat panel display. The most recent demonstration was of "supervised autonomy". In this case, the Tahoe follows a set of GPS way-points on a pre-planned course, but the video is sent to a supervisor located in a chase vehicle. If the supervisor observes an obstacle in the path the supervisor sends commands to either offset from the pre-planned route (to avoid the obstacle) or to stop.

7692-20, Session 3

3D vision upgrade kit for TALON robot

R. P. Edmondson, J. Vaden, J. F. Morris, B. Hyatt, L. Pezzaniti, D. B. Chenault, Polaris Sensor Technologies, Inc. (United States); J. L. Tchon, T. J. Barnidge, Rockwell Collins, Inc. (United States); S. Kaufman, Foster-Miller, Inc. (United States); D. Kingston, S. Newell, Concurrent Technologies Corp. (United States); B. Pettijohn, A. S. Bodenhamer, U.S. Army Research Lab. (United States)

In this paper, we report on the development of a 3D vision field upgrade kit for TALON robot consisting of a replacement flat panel stereoscopic display, and multiple stereo camera systems. An assessment of the system's use for robotic driving, manipulation, and surveillance operations was conducted. The 3D vision system was integrated onto a TALON IV Robot and Operator Control Unit (OCU) such that stock components could be electrically disconnected and removed, and

upgrade components coupled directly to the mounting and electrical connections. A replacement display, replacement mast camera with zoom, auto-focus, and variable convergence, and a replacement gripper camera with fixed focus and zoom comprise the upgrade kit. The stereo mast camera allows for improved driving and situational awareness as well as scene survey. The stereo gripper camera allows for improved manipulation in typical TALON missions. A number of representative scenarios were developed to determine which tasks benefited most from the added depth perception and to understand when the 3D vision system hindered understanding of the scene. A test was conducted at Fort Leonard Wood, MO. The upgrade kit, analysis of the test data, and the resulting performance assessment of the 3D vision system are reported.

7692-21, Session 3

Detecting and tracking moving objects from a moving platform using epipolar constraints

J. C. McBride, A. Ostapchenko, Charles River Analytics, Inc. (United States); H. Schultz, Univ. of Massachusetts (United States); M. S. Snorrason, Charles River Analytics, Inc. (United States)

One of the principal challenges in autonomous navigation for mobile ground robots is collision avoidance, especially in dynamic environments featuring both moving and non-moving (static) obstacles. A combination of scene sensing and path planning is required to avoid all obstacles, but moving objects (such as vehicles and pedestrians) present a particular challenge. To avoid a collision, the trajectory of a moving object must be known. This requires detection and tracking of all movers in the scene which is challenging because all points in the scene are in motion relative to a moving platform. Tracking is made difficult by occlusions, complex motion, and start-stop conditions. We present a solution for detecting and robustly tracking moving objects from a moving platform. We use a novel epipolar Hough transform to identify points in the scene which do not conform to the geometric constraints of a static scene when viewed from a moving camera. These points can then be analyzed in three different domains: image space, Hough space and world space, allowing redundant clustering and tracking of moving objects. We use a particle filter to model uncertainty in the tracking process and a multiple-hypothesis tracker with lifecycle management to maintain tracks through occlusions and stop-start conditions. The result is a set of detected objects whose position and estimated trajectory are continuously updated for use by path planning and collision avoidance systems. We present results from experiments using a mobile test robot with a forward looking stereo camera navigating among multiple moving objects.

7692-22, Session 3

Cognitive object recognition system

C. Raju, K. M. Varadarajan, N. Krishnamurthi, S. Xu, UtopiaCompression Corp. (United States); I. Biederman, The Univ. of Southern California (United States); T. D. Kelley, U.S. Army Research Lab. (United States)

UC has developed a framework, Cognitive Object Recognition System (CORS), inspired by current neurocomputational models and psychophysical research in which multiple recognition algorithms (shape based geometric primitives -'geons' and non-geometric feature-based algorithms) are integrated to provide a comprehensive solution to object recognition and landmarking. Objects are defined as a combination of geons, corresponding to their simple parts, and the relations among the parts. However, objects that are not easily decomposable into geons, such as bushes and trees, are recognized by CORS using "feature-based" algorithms. The unique interaction between these algorithms is a novel approach that combines the effectiveness of both algorithms and takes us closer to a generalized approach to object recognition. CORS allows recognition of objects through a larger range of poses using

geometric primitives and performs well under heavy occlusion - about 35% of object surface is sufficient. Furthermore, geon composition of an object allows image understanding and reasoning even with novel objects. With reliable landmarking capability, the system improves vision-based robot navigation in GPS-denied environments. Feasibility of the CORS system was demonstrated with real stereo images captured from a Pioneer robot. CORS will operate at real-time on processors that can be supported on small and large unmanned ground vehicles. The system can currently identify doors, door handles, staircases, trashcans and other relevant landmarks in the indoor environment.

7692-23, Session 6

Unmanned systems to support the human exploration of Mars

D. W. Gage, XPM Technologies (United States)

The time when we finally send humans to Mars, presumably a few decades from now, will not mark the end of the involvement of unmanned systems in the exploration of Mars. Instead, robots and other unmanned systems will play many critical roles on Mars, and the presence of humans will strongly affect the characteristics of the systems we build. In advance of the first human landings, the descendants of the Spirit and Opportunity rovers will survey candidate landing sites, identify and locate ice and mineral resources, establish power, communications, and navigations infrastructure, and likely construct underground habitats. Once humans have landed, mobile robots will preview sites for human exploration, identifying targets of interest and possible hazards. They will also perform construction tasks, and transport equipment and supplies, and people (as passengers or pilots).

These vehicles will differ from current planetary rovers in significant ways. Some of these will be work robots, requiring much more strength and power than survey rovers, and will be fueled by methane/oxygen engines or fuel cells. The presence of humans in the vicinity will permit proactive maintenance and repair, and allow teleoperation and operator intervention, supporting multiple dynamic levels of autonomy, and eliminating the current one command cycle per day. Installation of communications and navigation infrastructure will support structured and/or repetitive operations (such as excavation, drilling, or construction) within a "familiar" area with minimum operator attention.

This paper will discuss some of the factors involved in developing and deploying unmanned systems to make humans' time on Mars safer and more productive, efficient, and enjoyable.

7692-24, Session 6

Automatic payload deployment system

N. Pezeshkian, H. G. Nguyen, A. B. Burmeister, K. F. Holz, A. Hart, Space and Naval Warfare Systems Ctr. Pacific (United States)

The ability to precisely emplace stand-alone payloads in hostile territory has long been on the wish list of US warfighters. This type of activity is one of the main functions of special operation forces, often conducted at great danger. We eliminate this danger by transitioning the manual placement of payloads over to an automated placement mechanism by the use of the Automatic Payload Deployment System (APDS). Based on the Automatically Deployed Communication Relays (ADCR) system, which provides non-line-of-site operation for unmanned ground vehicles, by automatically dropping radio relays when needed, the APDS takes this concept a step further and allows for the delivery of a mixed variety of payloads. For example, payloads equipped with not only a radio repeater, but a camera and gas sensor, can be deployed in support of rescue operations of trapped miners. Battlefield applications may include delivering food, ammunition, and medical supplies to the warfighter. Covert operations may require the unmanned emplacement of a network of sensor for human-presence detection, before undertaking the mission. The APDS is well suited for these tasks. Demonstrations have been

conducted using an iRobot EOD PackBot in delivering a variety of payloads. The performance and results will be discussed in this paper.

7692-25, Session 6

Fusing ultra-wideband radar and lidar for small UGV navigation in all-weather conditions

B. M. Yamauchi, iRobot Corp. (United States)

Autonomous small UGVs have the potential to greatly increase force multiplication capabilities for infantry units. In order for these UGVs to be useful on the battlefield, they must be able to operate under all-weather conditions. For the Daredevil Project, we have explored the use of ultra wideband (UWB) radar and LIDAR for all-weather navigation capabilities. UWB radar provides the capability to see through rain, snow, smoke, and fog. LIDAR provides greater accuracy and resolution in clear weather but has difficulty with precipitation and obscurants. By fusing the sensor data from the two sensors we can combine the advantages of the two sensor modalities. We present research on obstacle detection and avoidance in obscured environmental conditions and shows how the information from UWB radar and LIDAR can be fused in a way that allows the integrated system to outperform a system based on either radar or LIDAR alone.

7692-26, Session 6

Experiment to evaluate assistive behaviors for small robot operation

C. S. Pierce, D. Baran, B. A. Bodt, U.S. Army Research Lab. (United States)

Man portable robots have been fielded extensively on the battlefield to enhance mission effectiveness of soldiers in harms way. The robots that have been deployed to date have been tele-operated. It is generally agreed that development of assistive behaviors for robots would alleviate some of the workload for the soldier and reduce strain on the communications network. While full autonomy is the eventual goal, a range of assistive capabilities such as obstacle detection, obstacle avoidance, waypoint navigation, automated mapping, geolocation, optical change detection, and target tracking can be fielded sooner. These capabilities increase the level of autonomy on the robots so that they can reduce the workload on the soldier and present a partial solution to full autonomy.

The focus of this paper is to show how assistive behaviors can have a positive impact on tele-operation of a robot. ARL conducted scientifically rigorous experiments to quantifiably assess robot performance with assistive behaviors. The experiments helped to determine a baseline for tele-operation and to evaluate the benefit of Obstacle Detection and Obstacle Avoidance (OD/OA) vs. tele-operation and OD/OA with Open Space Planning (OSP) vs. tele-operation. The experiment revealed that there were reduced collisions with OD/OA but not necessarily reduced time to completion. OD/OA with OSP also had reduced collisions. However, the time to completion was very close to tele-operation. These results are presented and analyzed in the paper.

7692-27, Session 7

Challenges in unmanned aircraft systems (UAS): from controller design to integration into the national airspace

K. P. Valavanis, Univ. of Denver (United States)

ABSTRACT: Unmanned systems in general and unmanned Aircraft Systems (UAS) in particular, have seen unprecedented levels of growth during the last decade even though their 'utilization' has been the subject

of criticism at times. However, it has been argued that UAS applications in civilian and public domains will be dominant in the future, focusing on fire detection, forest protection, crime prevention, power line inspection, environmental monitoring, emergency response and traffic monitoring, to name just a few application domains. Rotary wing UAS, unmanned helicopters, because of their ability to hover, take off from, and land almost anywhere, offer the best and a very viable solution to the 'eye-in-the-sky' alternative. Therefore: Focusing on unmanned helicopters, and putting emphasis on controller/navigation system design, a series of controllers, from simple PID, fuzzy-PID, to multivariable LQG, Hμ, robust and Model Predictive Control (MPC), as well as a novel discrete backstepping controller are presented and tested for several different flying profiles. In addition, a novel nonlinear MPC augmented with a recurrent Neural Network for learning is proposed for autonomous vertical autorotation of unmanned helicopters post main/tail rotor failures, with extensions to manned helicopters, too. Recommendations for deriving equivalent levels of safety for UAS leading to their potential integration into the National Airspace System are discussed based on improved reliability and fault tolerance requirements.

7692-28, Session 7

Experiments with autonomous mobile radios for wireless tethering in tunnels

K. L. Moore, M. D. Weiss, Colorado School of Mines (United States)

"For organized session on "Intelligent Behaviors" of F.L. Lewis and G. Hudas

Tunnels are a challenging environment for radio communications. In this paper we consider the use of autonomous mobile radio (AMR) nodes to provide wireless tethering between a base station and a leader in a tunnel exploration scenario. Using a realistic, experimentally-derived underground radio signal propagation model and a tethering algorithm based on a consensus variable protocol for AMR motion control, we present experimental results involving a tele-operated leader with two followers. By viewing video feedback from the leader, relayed via the two followers, an operator uses a joystick to drive the leader down a tunnel while the followers autonomously space themselves so as to achieve equal radio distance between each entity in the chain from the base to the leader. In addition to the algorithms and experimental results, we also describe the unmanned ground vehicles used in the experiment, which are commanded via a generic UGV autopilot we have developed.

7692-29, Session 7

A Q-learning approach to online unmanned air vehicle (UAV) navigation for target detection and classification

S. Ferrari, S. G. Daugherty, Duke Univ. (United States)

This paper develops an online Q-learning approach to Unmanned Air Vehicle (UAV) navigation for sensing and surveillance applications. The approach develops an adaptive navigation algorithm for a reconfigurable sensor installed on an UAV. The UAV-sensor is deployed for the purpose of detecting and classifying multiple static targets on the ground. Therefore, UAV navigation can be considered as a geometric sensor-path planning problem, because the geometry and position of the sensor's field of view determine what targets can be detected and classified at any given time. Sensor planning is concerned with determining a policy for gathering sensor measurements to optimize a sensing objective, such as target detection and classification. When a sensor is installed on a mobile platform, an important part of the problem is determining the path that enables the optimal measurement sequence. Several approaches have been developed for planning the path of mobile robots equipped with sensors to enable navigation and obstacle avoidance. However, these methods are not directly applicable to mobile sensors whose primary goal is to support a sensing objective. The reason is that they focus on

how the sensor measurements can best support motion, rather than focusing on how the motion can best support sensor measurements. The approach presented in this paper learns the optimal motion via a Q-function that represents the information-value to-go, without an explicit model of the sensor's measurements and dynamics. The approach is demonstrated through an UAV-based IR sensor that is deployed to detect and classify landmines in variable environmental conditions.

7692-30, Session 7

Unmanned aircraft systems as wingmen

R. D. Garcia, U.S. Army Research Lab. (United States); L. E. Barnes, The Univ. of Texas at Arlington (United States)

This paper introduces a concept towards integrating manned and Unmanned Aircraft Systems (UAS) into a highly functional team though the design and implementation of 3-D distributed formation/flight control algorithms with the goal to act as wingmen for manned aircraft. This type of formation/flight control has several distinctions from current UAS control methods. First, manned aircraft must have the ability to direct an entire group of UAS with minimal information and sparse updates. Second, given the limited knowledge about manned aircraft's intentions, UAS must be able to predict the intent of the manned aircraft. Third, coordination algorithms should utilize standard operating formations and maneuvers to alleviate resistance manned pilots have towards integrating UAS into the team. Last, implementations should support splinter groups of unmanned vehicles intended to extend the situational awareness of the team or act as safeguard between any suspected threat and the manned vehicles.

The proposed work coordinates UAS members by utilizing artificial potential functions whose values are based on the state of the unmanned and manned assets including the desired formation, obstacles, task assignments, and perceived intentions. The overall unmanned team geometry is controlled using potential fields and limiting functions. Individual UAS utilize fuzzy logic controllers for stability and navigation as well as a fuzzy reasoning engine for intention prediction.

Approaches are demonstrated in simulation using the commercial simulator X-Plane and controllers designed in Matlab/Simulink. Experiments include trail and right echelon formations as well as manned vehicle protection and splinter group surveillance.

7692-31, Session 7

Fault tolerant formation control of nonholonomic mobile robots using online approximators

B. T. Thumati, T. A. Dierks, S. Jagannathan, Missouri Univ. of Science and Technology (United States)

For unmanned systems, it is more important that the controller possess fault tolerant capability in the event of unforeseen faults. Therefore in this paper, intelligent control of nonholonomic mobile robot formations in the presence of unknown faults is undertaken using backstepping technique and online approximators to accommodate the dynamics of the individual robots and the formation. First, a fault tolerant kinematic/torque leader-follower formation control law is developed for the leader and follower robots under the assumption of normal operation (no faults), and the stability of the individual robots and the formation is verified using Lyapunov methods. Subsequently, in the presence of state faults such as an actuator fault, flat-tire etc., an online fault detection and accommodation (FDA) scheme is derived to mitigate the effects of a fault which could be incipient or abrupt in nature by modifying the nominal controller. In other words, the original controller is reconfigured by augmenting the original control law with an additional term to minimize the effects of the fault. This additional term is a function of the unknown fault dynamics which are recovered using the online learning capabilities of online approximators, and the asymptotic convergence of the FDA scheme and the formation errors in the presence of faults is rigorously

shown using Lyapunov methods. Numerical results are provided to verify the theoretical conjectures.

7692-32, Session 7

Control of an indoor autonomous mobile communications relay

B. Griffin, R. Fierro, I. Palunko, The Univ. of New Mexico (United States)

Unmanned ground vehicles (UGVs) have become a desired asset for operations in urban environments whether it is soldiers searching a potentially dangerous building, exploring a cave, or first-responders performing search and rescue amongst wreckage. Typically a ground station will be external to the building from which an operator can control the robot and receive imagery from the UGV. A problem faced by all of these mobile robots is that as the UGV descends further into a building, the communications link degrades. High-frequency digital communications are the preferred communication link between the robot and ground station, but they are limited to line-of-sight (LOS) operations and hence, difficult to maintain in urban environments as the RF signal is susceptible to interference, multipath, and attenuation. One way of solving this problem is to add communication relays between the ground station and robot. The ideal relay should operate without user intervention or even knowledge, should be a hybrid system that switches in and out of operation as necessary (i.e., use the direct link when link quality is good and then switch in the communication relay when necessary), should optimize the communication link, and should perform recovery autonomously (i.e., return to base station or mobile robot).

Little work has been done regarding the use of communication relays in indoor or GPS-denied environments. Previous work has focused on using static relays dropped by the UGV as it proceeds. Some additional work is in progress investigating the use of UGVs as indoor mobile routers. This paper proposes the use of a quadrotor UAV to function as such a communication relay. The quadrotor optimizes its communication link using a novel potential field methodology based on antennae diversity. To this end we use four directional antennas, one placed at each of rotors on the quadrotor. Each antenna can then provide a Signal-to-Noise Ratio (SNR) measurement without any additional communication. SNR measurements provide a robust indictor of the available bandwidth and quality of each link, even in the presence of non-uniform disturbances that may be due to noise or LOS obstruction. The antenna with the highest SNR is chosen and if the SNR is still not sufficient, the quadrotor can move to improve the link. A potential field is created where higher SNR antennas will signal more positive fields and conversely, walls and other obstacles will create a negative field. The resulting artificial potential field guides the quadrotor so as to improve the SNR while avoiding collisions. Simulation results and hardware experiments are provided to verify the proposed control methodology using Pioneer 3-AT mobile robots and an AscTech Hummingbird quadrotor.

7692-33, Session 7

Reinforcement learning and adaptive control for cooperative networked teams

F. L. Lewis, The Univ. of Texas at Arlington (United States); G. R. Hudas, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States)

U.S. Army Training and Doctrine Command (TRADOC) Pamphlet 525-66 identifies Force Operating Capabilities required for the Army to fulfill its mission for a networked Warfighter concept. Two such capabilities are Battle Command and Battle-space Awareness for which there are expectations that networked teams will perform in a reliable manner under changing mission requirements, varying platform reliability, and resource faults. Battlefield or disaster area teams may be heterogeneous networks consisting of interacting humans, ground sensors, and unmanned airborne or ground vehicles (UAV, UGV). Agreement must

be reached among team members about objectives, group motions, synchronization of efforts for multiple missions, and use of shared services of resources to augment the capabilities of the remote-site mission commander and on-site war-fighter. This requires a scalable, deployable and mobile networking consensus capability that supports mission tailoring, force responsiveness and agility, ability to change missions without exchanging forces, and general adaptability to changing battlefield conditions.

Such scenarios require intelligent and adaptive mechanisms for reaching agreement among team members based on information received from only a few other members. Though data is transmitted only locally, an overall or global agreement must be reached for the team to perform assigned missions free of conflict. Disaster and Battlefield scenarios involve networked platforms that have disturbances, unmodeled nonlinear dynamics, and imprecise responses to commands. Traditional consensus algorithms assume very simple dynamics with no uncertainties or disturbances.

In this paper we present schemes for agreement consensus that have adaptive learning features to learn about unknown dynamics and reject disturbances, so that a close enough consensus is reached for practical purposes. We describe rigorous mathematically justified networked agreement algorithms that deal with practical modeling inaccuracies and disturbances in the field that are normally ignored in the literature. This allows more suitable response for agreement and team decisions under dynamically changing conditions.

7692-34, Session 8

LS3: quadruped robot designed to lighten the load for dismounted warriors

M. Raibert, Boston Dynamics (United States)

The assault load of the average US Marine ranges from 95 to 135 lbs, whereas the recommended load is 50lbs. One approach to lighting the load is to develop legged robots that can carrying a portion of Warfighter's load while traveling anywhere the dismounted warrior can go.

Boston Dynamics is developing the LS3 four-legged rough-terrain robot with that mission in mind. When fully developed, LS3 will weigh about 600 lbs and carry 400 lbs of payload and 100 lbs of fuel - enough fuel for a 20-mile, 24-hour mission. It will travel at human walking speeds of 3-4 mph, but will also be able to go faster for a few minutes at a time. The LS3 will travel fully loaded on diverse terrain, negotiating rocks, sand, mud, hills and snow and will wade through streams. LS3 will use computer vision and LDIAR to automatically follow a human leader, while the leader remains focused on his or her mission. The development of LS3 is being funded by DARPA and the US Marine Corps.

7692-35, Session 8

The Autonomous Platform Demonstrator (APD): goals, mobility testing results, and outlook

J. E. Bares, Carnegie Mellon Univ. (United States)

No abstract available

7692-36, Session 8

Urban hopper

J. R. Salton, Sandia National Labs. (United States)

The Defense Advanced Research Projects Agency (DARPA) began supporting the development of small hopping robots at Sandia National Laboratories (SNL) several years ago. The original hopping robot concept had one mobility mode: aim and hop. This concept has now evolved into

a small wheeled, unmanned ground vehicle with an integrated hopping capability. This approach achieves exceptional mobility by efficiently driving along the ground, but when necessary, hopping over or onto obstacles over 50 times its own height. DARPA's Strategic Technology Office is funding an ongoing program to develop the wheeled hopping technology called the Urban Hopper. The program is in its third phase and is now focused on advanced capabilities as well as transition. DARPA and SNL are working to make the Urban Hopper more robust for field operations and have joined with industry partner Boston Dynamics to take the next step towards transitioning the capability into the field. In addition to this, advanced sensors and software algorithms are being integrated into the vehicle design to increase the operational capabilities. This presentation will discuss the general development and capabilities of the Urban Hopper and the current state of the technology.

7692-37, Session 8

PETMAN: a humanoid robot for chem/bio suit testing

R. R. Playter, Boston Dynamics (United States)

Reviewers: I must submit a previously approved press release as my abstract. If accepted to SPIE, I will update the abstract to reflect current status with additional technical detail.

PETMAN will be an anthropomorphic robot for testing chemical protection clothing. Unlike previous suit testers, which had to be supported mechanically and had a limited repertoire of motion, PETMAN will balance itself and move freely; walking, crawling and doing a variety of suit-stressing calisthenics during exposure to chemical warfare agents. PETMAN will also simulate human physiology within the protective suit by controlling temperature, humidity and sweating when necessary, all to provide realistic test conditions.

Natural, agile movement is essential for PETMAN to simulate how a soldier stresses protective clothing under realistic conditions. The robot will have the shape and size of a standard human, making it the first anthropomorphic robot that moves dynamically like a real person.

The development program has a 13 month design phase followed by a 17 month build, installation and validation phase, with delivery of the robot taking place in 2011. Boston Dynamics' partners for the program are Midwest Research Institute (MRI), Measurement Technology Northwest, Smith Carter CUH2A (SCC) and HHI Corporation.

7692-38, Session 8

Agile and dexterous robot for inspection and EOD operations

D. A. Handelman, American Android Corp. (United States)

This paper presents on-going development of the All-Terrain Biped/EOD robot, an unmanned ground vehicle with wheels, legs and arms capable of driving, crawling, walking and manipulating objects for inspection and explosive ordnance disposal tasks. Advanced limb coordination technology provides independent control of balance and posture, and intelligent behaviors automatically select locomotion mode based on the operational environment. Previous work involved the preliminary design of an ATB/EOD prototype. Simulated locomotion and manipulation behaviors were developed as well as an intuitive operator interface. Current development includes construction and testing of the hardware prototype. Performance goals include driving on flat terrain, crawling on steep terrain, walking on stairs, opening doors and grasping objects. Anticipated benefits of the terrain-adaptive mobility and dual-arm dexterity of the ATB platform include increased robot agility and autonomy for EOD operations, reduced operator workload and reduced operator training and skill requirements.

7692-39, Session 8

Toward humanoid robots for operations in complex urban environments

J. E. Pratt, Institute for Human and Machine Cognition (United States)

Many infantry operations in urban environments, such as building clearing, are extremely dangerous and difficult and often result in high casualty rates. Despite the fast pace of technological progress in many other areas, the tactics and technology deployed for many of these dangerous urban operation have not changed much in the last 50 years. While robots have been extremely useful for improvised explosive device (IED) detonation, under-vehicle inspection, surveillance, and cave exploration, there is still no fieldable robot that can operate effectively in cluttered streets and inside buildings.

Developing a fieldable robot that can maneuver in complex urban environments is challenging due to narrow corridors, stairs, rubble, doors and cluttered doorways, and other obstacles. Typical wheeled and tracked robots have trouble getting through most of these obstacles. A bipedal humanoid is ideally shaped for many of these obstacles because its legs are long and skinny. Therefore it has the potential to step over large barriers, gaps, rocks, and steps, yet squeeze through narrow passageways, and through narrow doorways. By being able to walk with one foot directly in front of the other, humanoids also have the potential to walk over narrow "balance beam" style objects and can cross a narrow row of stepping stones.

We describe some recent advances in humanoid robots, particularly recovery from disturbances, such as pushes and walking over rough terrain. Our disturbance recovery algorithms are based on the concept of Capture Points. An N-Step Capture Point is a point on the ground in which a legged robot can step to in order to stop in N steps. The N-Step Capture Region is the set of all N-Step Capture Points. In order to walk without falling, a legged robot must step somewhere in the intersection between an N-Step Capture Region and

the available footholds on the ground. We present results of push recovery using Capture Points on our humanoid robot M2V2.

7692-40, Session 8

On-board SLAM map optimization for indoor UAV using a laser range finder

M. Alpen, K. Frick, J. Horn, Helmut-Schmidt Univ. (Germany)

We developed a SLAM algorithm for on-board application to an indoor UAV with a laser range finder based on orthogonal SLAM. In this case lines that are parallel or orthogonal to each other are mapped, because the main structure of most indoor environments can be represented by these lines.

The current scan of the laser range finder is integrated into the global map without any iteration. This algorithm is favorable regarding the computing time in comparison to the known ICP or PSM methods but the resulting estimation of the difference between current and former scan has a slightly larger variance. This would cause some inaccuracy of the global map which leads to an error propagation during the robot's mission. Therefore an optimization algorithm reducing this inaccuracy is essential. Within this optimization lines with the same orientation and an overlapping in one of the two possible coordinates of a 2D-plane are merged if their distance is below a certain threshold value.

To get an accurate map close to the reality, the history of the map and the current position of the robot are considered in the optimization process because the variance of the laser range finder is proportional to the distance between sensor and object. The algorithm has to compute the position of the resulting merged lines taking the uncertainty of each line into account.

Our work is validated on a quadrotor with Laser range finder and enables an indoor UAV to act autonomously in an unknown indoor environment.

7692-41, Session 8

Optimal powering schemes for legged robotics

P. L. Muench, D. Bednarz, G. P. Czerniak, U.S. Army Research, Development and Engineering Command (United States)

Although bio-inspired legged robots have advantageous mobility, they can be very inefficient. Their intrinsic walking mobility is sometimes outweighed by the inefficiency of their drive-train. Some of these inefficiencies are due to collision losses, but they are also due to suboptimal powering schemes. This paper addresses the powering schemes and seeks to clearly delineate an optimal solution to powering the walking motion of a two-legged or biped walker. We examine a simplified model of locomotion based on the inverted pendulum to find the control that optimizes time and energy cost. Using Pontryagin's Maximum Principle, we dissect the cost function, the state equation, co-state equation, and control input constraints to describe the optimal control. The result of the paper shows an "on-off" control, and we describe the "switching curve" between these extremes. It is not possible to find a complete closed-form solution for the problem, and numerical methods, such as dynamic programming must be used for simulation and visualization of the results.

7692-42, Session 8

R Gator: an unmanned utility vehicle

S. J. Moorehead, Deere & Co. (United States); C. K. Wellington, Carnegie Mellon Univ. (United States); H. Paulino, John Deere SouthEast Engineering Ctr. (United States); J. F. Reid, Deere & Co. (United States)

The R Gator is an unmanned ground vehicle built on the John Deere 6x4 M Gator utility vehicle chassis. The vehicle is capable of operating in urban and off road terrains and has a large payload to carry supplies, wounded or a marsupial robot. The robotic drive by wire system was added on top of the existing mechanical linkages so if the electronics fail, the vehicle can still be driven manually.

The R Gator has 6 modes of operation: manual driving, teleoperation, waypoint, direction, playback and silent sentry. In direction drive the user specifies a direction for the robot. It will continue in that direction, avoiding obstacles, until given a new direction. Playback allows previously recorded paths, from any other mode including manual, to be played back and repeated. Silent sentry allows the engine to be turned off while cameras, computers and comms remain powered by batteries. Vehicle motion is not possible, but valuable surveillance information can still be collected.

The user interface consists of a wearable computer, monocle and X Box 360 controller. All functions of the R Gator can be controlled by the 360 controller, using at most 2 button presses. This easy to use user interface allows even untrained users to control the vehicle.

This paper details the systems developed for the R Gator, focusing on the novel user interface and the obstacle detection system, which allows autonomous operations in tall grass. Designs for a new 4 wheel, independent suspension chassis version are also presented.

7692-43, Session 8

Research and development of spherical underwater vehicles

X. Lan, H. Sun, Q. Jia, H. Li, Beijing Univ. of Posts and Telecommunications (China)

This paper summarizes research status of spherical underwater vehicles. Spherical underwater vehicles are a kind of special underwater vehicles which have spherical hulls. The reason for the spherical configuration

choice is two-fold. First, the spherical shape is axially symmetric and provides equivalent drag in any direction which simplifies the hydrodynamic equation of motion. Second, the simplicity of shape allows easy modification to the shape to emulate different vehicle configurations.

Some spherical underwater vehicles have external thrusters, and some have ballast systems.Because of the difference in structure, the control schemes of some typical spherical underwater vehicles are introduced respectively:

1)Omni-Directional Intelligent Navigator (ODIN) is a closed-framed underwater spherical vehicle with eight thrusters.Unique to ODIN's construction is the control from an eight dimensional thrust to move in six degrees-of-freedom.This construction puts redundancy into the system in case of thruster failure.Sometimes ODIN only use the vertical thrusters or the horizontal thrusters.In that situation, ODIN is underactuated.

2)The Internally Actuated, Modular Bodied, Untethered Submersible (IAMBUS) is owned by Virginia Polytechnic Institute and State University. IAMBUS can mimic a spacecraft, vehicle attitude control is provided by three orthogonally mounted reaction wheels.Its depth control is accomplished through the use of a double-plunger type ballast system.

3)BYSQ-2 is an underwater spherical vehicle only with one thruster, its attitude control is mainly about the underwater inverted pendulum control problem.

Drag reduction is studied in FLUENT by making holes in the outside surface of the spherical hull according to the golf ball theory.

7692-60, Poster Session

Device capable small arms ammunition for unmanned systems

N. P. Bergeron, J. W. Sweeney, C. G. Wilson, Louisiana Tech Univ. (United States)

This paper reports on the development of a novel form of device capable caseless small arms ammunition. Conventional small arms ammunition is subject to lateral and radial accelerations in the 50kG to 120kG regime. This limits the type, construction, and materials of MEMS devices that are suitably durable for use in small arms ammunition. As opposed to trying to develop new forms of MEMS to tolerate the large accelerations, we have developed new ammunition that has reduced lateral and radial accelerations, while maintaining lethality and range. This ammunition is drag stabilized and powered by rocketry-based solid fuels, and is designed to fit within the size and weight envelopes established by existing small arms. The combination of rocket propellant and drag stabilization serves to reduce the accelerations imparted to imbedded devices. Through this technique, radial accelerations are eliminated, while lateral accelerations are reduced by over an order of magnitude compared to standard military issue small arms ammunition. This enables the use of Commercial Off the Shelf (COTS) MEMS devices, which in turn greatly increases the overall capabilities of the ammunition. Also, this ammunition enables new forms of electronically fired guns with lightweight polymer barrels. The lightweight nature of the gun, combined with the high rates of fire allowed by electronic ignition and the low recoil associated with rocket propellant, makes this form of ammunition uniquely suited to use with unmanned systems.

7692-61, Poster Session

Pressurized structures-based hybrid unmanned aerial systems

H. L. Edge, U.S. Army Research Lab. (United States)

The objective of this research is to explore, develop, and demonstrate the feasibility of pressurized structures based (PSB) technology for hybrid unmanned aerial vehicles (UAV). In other words, the UAV will be designed such that a considerable percentage of its weight is supported by or constructed from inflatable structures containing air or helium. PSB

based airframes will allow UAVs to be built that are more energy efficient, and quieter because of their reduced mass. If most of the aircraft volume is pressurized, buoyancy may be used to reduce the weight of the aircraft as well. Using modern materials and new designs to take advantage of their light weight and high strength, it may be possible to build low drag airframes with a high percentage of buoyancy with relatively modest dimensions. In addition to being more efficient, the PSB airframes may also have very desirable slow speed flight characteristics, hovering, and vertical takeoff and landing. These improved flight characteristics will greatly increase the capability of UAVs and will allow them to perform missions that current conventional fixed-wing UAVs cannot. As an added bonus, PSB UAVs may be designed to be very portable, and will likely not require additional support equipment such as catapults for takeoff or runways for landings. This paper will document the benefits of PSB airframes demonstrated through simulation and comparison with a prototype research partially buoyant hybrid UAV.

7692-62, Poster Session

A reusable robotic grasp creator

Y. Li, C. Pholsiri, J. Keesling, N. Tardella, J. English, Energid Technologies (United States)

Generating accurate robotic grasps is a recurring challenge for researchers and robot users. Energid Technologies is developing a Graphical User Interface (GUI) tool and algorithms embodied in a reusable software toolkit to quickly and easily create grasps. The method is generic and works with all types of robotic hands, manipulators, and mobile platforms. Vision, position control, force control, and collision avoidance algorithms are integrated into the process, and successful grasp parameters are stored in a database for later real-time application. Grasps in the database are associated with an object that can be looked up by shape. This article describes how the grasps are created in the Energid system using convenient human interfaces, novel ways to constrain the robotic hand, and real-time simulation of the grasping process. The editing of grasps, once created, is also discussed. Special emphasis is given to the integration of force control with the grasp scripting process. The force control system accommodates a variety of established algorithms and allows new user-defined algorithms, which can apply to many types of force/torque sensors. Special emphasis is also given to vision-based tracking. The vision system provides object identification to select an appropriate grasp from the database, and it provides 3D tracking to guide the grasp process. For objects similar to those used to create grasps, the vision system can be used to retrieve a grasping sequence from the database through shape similarity. Simulation and hardware study results are presented based on the Schunk SDH hand and LWA arm.

7692-63, Poster Session

Optimal trajectory planning for the Herding Problem: a continuous time model

S. A. Shedied, Egyptian Armed Forces (Egypt)

This paper introduces a different representation of pursuit-evasion game. In which, a pursuer is trying to herd the evader to certain location over the shortest path. The paper gives a continuous time model representation of the problem and the optimal trajectory that the pursuer showed follow is obtained.

First introduction of the problem is illustrated in the first section. Then a mathematical model of the problem is introduced in the next section. After that, mathematical derivation of the optimal trajectory is presented. Finally, some of the simulation results are presented.

7692-66, Poster Session

Manipulability analysis of a two-link space robot using differential geometry method

Y. Zhang, H. Sun, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

Space robot is a special robotic system which is expected to perform important tasks in space, like servicing satellites. However, the application of space robots in space creates a number of technical challenges because of the dynamic coupling between manipulator and base. The dynamics coupling between manipulator and base will affect the performance of the manipulator. This phenomenon makes it difficult to control the manipulator, adversely affects the manipulator's manipulability.

For the dynamic coupling characteristic of the space robot , the researching method of robot used on ground can not be directly applied to the space robot. Although reaearchers developed manny methods to study the space robot, earch of these methods has it's limitations.

In this paper, morden differential geometry method is applied to study the motion characteristic of space robot. The kinematic model of the space robot is constructed by using the moving frame method. Based on this kinematic model, a volume element concept which is an invariant is developed to evaluate the manipulability and disturbance of a space robot system. In the contruction process of volume element, the momentum conservation is also considered. By using the volume element concept, a two link space robot is used to discuss the application of this researching metod, and the manipulability of manipulator and it's influence on the base are analyzed.

In comparison to other researching method, this differential geometry method is shown to be useful in performing manipulability and disturbance analysis for space robot in a zero-gravity environment and is more directly and intelligible than the other methods. This method is a new theoretical approach in space robot research which is largely theoretical at this point in time.

7692-68, Poster Session

Wheel load sensing for controlled drifting

J. R. Rogers, U.S. Military Academy (United States)

A low-cost method of measuring dynamic vertical wheel reaction forces in automotive vehicles is presented. Loads are used to improve the performance of a drifting maneuver. The transfer of vertical loads from wheel-to-wheel while braking, accelerating, and cornering is proposed as a parameter to control drifting. The system is implemented on the USMA small, high-speed UGV, a 1/10 scale radio controlled model four-wheel-drive truck. Displacements of the suspension components on each wheel are measured by Hall Effect sensors. Data is logged while driving on dirt. MATLAB is used in a post-process analysis of the logged data to estimate dynamic loads. The potential use of the system to develop autonomy of unmanned vehicles is considered. A mass-spring-damper model of the suspension used to estimate wheel loading from suspension displacement is presented.

7692-69, Poster Session

Heuristics-enhanced dead-reckoning (HEDR) for accurate position tracking of tele-operated UGVs

J. Borenstein, R. J. Miller, A. Borrell, D. L. Thomas, Univ. of Michigan (United States)

This paper introduces a method for the accurate tracking of tele-operated unmanned ground vehicles (UGVs). Our proposed method, called "Heuristics-enhanced Dead-reckoning," (HEDR) facilitates tele-operation

of UGVs by providing the operator a GPS-like visual trajectory when the UGV is driven inside buildings, where GPS is unavailable. This is useful since it conveys to the operator the momentary heading and position of the UGV in the context of a "breadcrumb trail" (i.e., a plot of a trajectory that evolves real-time). When used inside buildings, our heuristics method completely eliminates heading errors for runs of unlimited duration. Of course, the elimination of heading errors also greatly reduces position errors, which are usually and predominantly the result of heading errors.

The HEDR method makes use of certain environmental features that are true for perhaps more than 99% of all man-made structures. Specifically, HEDR makes the heuristic assumption that most travel inside buildings happens along straight lines, and that most turns at the intersection of corridors have 90-degree angles.

The strength of our HEDR method lies in the fact that it can tolerate substantial deviations from the heuristic assumptions. To do so, HEDR monitors the drive characteristics in real-time. When HEDR detects motion that is not compliant with the heuristic assumptions, HEDR suspends its error correction. Then, when motion becomes compliant again, HEDR resumes the correction of heading errors and reduces them to zero - over time. Typical results are near-zero heading errors and position errors <1% of distance traveled.

7692-70, Poster Session

Monocular panoramic 3D reconstruction based on a particle filter

F. Pagel, Fraunhofer-Institut für Informations- und Datenverarbeitung (Germany)

This paper adresses the issue of generating a panoramic view as well as a panoramic depth map using only a single camera. The proposed algorithm first estimates the egomotion of the camera. Based on this information a particle filter is designed that approximates the 3D structure of the scene. Hence, 3D scene points are modeled probabilistically.

Then the points are accumulated in a cylindric coordinate system. The probabilistic representation of 3D points is used to handle the problem of visualizing occluding and occluded scene points in a noisy environment to get a stable data visualization. This approach can be easily extended to calibrated multi-camera applications (even with non-overlapping field of views).

7692-71, Poster Session

Exploiting uncalibrated stereo on a UAV platform

M. Banish, J. Heym, B. Hyatt, D. B. Chenault, M. H. Rodgers, Polaris Sensor Technologies, Inc. (United States)

Uncalibrated stereo imagery experimental and analytical results are presented for path planning and navigation. An Army Research and Development Engineering Command micro-size UAV was outfitted with two commercial cameras and flown over varied landscapes. Polaris Sensor Technologies processed the data post flight with an image correspondence algorithm of their own design. Stereo disparity (depth) was computed despite a quick assembly, image blur, intensity saturation, noise and barrel distortion. No camera calibration occurred. Disparity maps were computed at a processing rate of approximately 5 seconds per frame to improve perception. Disparity edges (treeline to ground, voids and plateaus) were successfully observed and confirmed to be properly identified. Despite the success of localizing these disparity edges, sensitivity to saturated pixels, lens distortion, and defocus were strong enough to overwhelm more subtle features such as the contours of the trees, which should be possible to extract using this algorithm. These factors are being addressed. The stereo data is displayed on a flat panel 3D display well suited for a human machine interface in field applications. Future work will entail extraction of intelligence from acquired data and the overlay of such data on the 3D image as displayed.

7692-72, Poster Session

A technology for unified transition from manned to unmanned teams

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

An approach is offered where an open team can be effectively tasked in a higher-level Distributed Scenario Language (DSL) setting main operations and decisions to be undertaken in distributed environments, often without details of possible implementation system organization, which may not be known in advance. Subordination between individuals, creation of operational infrastructures, communication and synchronization can be accomplished at runtime by formal rules during reading, decomposing, replicating, modifying, and exchanging scenario parts. The dynamically networked team behaves as parallel distributed interpreter of mission scenarios written on the fly and starting from any unit, timely reacting on changing goals, environments, and group composition. The team members can be manned or unmanned, with communications ranging from visual or voice to electronic; this providing a unified transition to fully robotic solutions, if required. It is also possible to set up in DSL any system organization explicitly, with active nodes and links, local and global command and control, effectively expressing other existing parallel and distributed computational and control models within the same simple formalism. Any group behavior-from loose swarming to global goal-driven behavior, situation awareness and making autonomous decisions-can be expressed and integrated too. The paper will reveal details of DSL and its networked interpreter, which can be installed in laptops, mobile phones, sensors and mobile robots, integrating manned and unmanned components into a universal spatial machine operating with both information and matter. Sapaty, P., "Providing spatial integrity for distributed unmanned systems", Proc. ICINCO 2009, Milan, Italy, 2009. www.amazon.com sapaty in books.

7692-73, Poster Session

Haptic feedback for improved tele-operated manipulation

W. H. Huang, M. R. Claffee, iRobot Corp. (United States); W. A. Aviles, J. Miller, Novint Technologies, Inc. (United States); M. Buehler, iRobot Corp. (United States)

Manipulation of objects via teleoperation is difficult, particularly on EOD-class robot arms. Skillful manipulation requires feeling when objects are in contact and how strongly an object is grasped. We have developed a prototype system to provide force feedback to a teleoperator for manipulation tasks. Our haptic controller is based on a low-cost commercially available game controller, the Novint Falcon, that provides 3DOF force feedback to the operator. We have augmented the Falcon with a custom grip that provides 2DOF rotational and 1DOF gripper control with force feedback. We have integrated this controller with specially designed fingers for an iRobot PackBot EOD-arm gripper that have integrated force sensing. The resulting system allows an operator to feel when the gripper (or an object held in the gripper) contacts another object and how much gripping force is applied to the object. We describe our hardware design, algorithms for force-feedback control, and the results of experimental evaluation on manipulation tasks.

7692-75, Poster Session

Friction compensation of the spherical mobile robot based on neural network sliding mode control

C. Shi, H. Sun, X. Lan, Y. Zheng, Beijing Univ. of Posts and Telecommunications (China)

The spherical mobile robot can perform straight line motion, zero turning radius, obstacle avoidance, and circular motion. Traditional dynamic

models of spherical robot were established in ideal condition that didn't consider the influence of the slipping and joint friction which will influence the motion performance greatly in some condition.

In this paper, the dynamic models of the spherical robot in undesirable condition were established based on the Kane method. The motion performance of the spherical robot in slipping condition was analyzed by simulation. Through the results, we can find that the motion was very unstable. Then, based on the RBF neural-network, the uncertainty dynamic model was established by neural network on-line identification. Meanwhile, based on the sliding-mode variable structure control method, the robust motion controllers were designed. At last, The feasibility of this method is validated by simulation and experimentation results.

7692-77, Poster Session

Cooperative energy harvesting for long-endurance autonomous vehicle teams

S. F. Page, J. D. Rogers, D. R. Myatt, K. May, D. L. Hickman, M. I. Smith, Waterfall Solutions Ltd. (United Kingdom)

This paper considers the exploitation of energy harvesting technologies for teams of Autonomous Vehicles. Traditionally, the optimisation of information gathering tasks such as searching for and tracking new targets, and platform level power management, are only integrated at a mission-management level. In order to truly exploit renewable-energy harvesting technologies which are emerging in both the commercial and military domains (for example the 'EATR' robot and next-generation solar panels), the sensor management and power management processes must be directly coupled. This paper presents a novel non-myopic sensor management framework which addresses this issue through the use of a predictive platform energy model. Energy harvesting opportunities are modelled using a dynamic spatial-temporal energy map which is subject to uncertainty and sensor and platform actions are optimised according to global team utility. The framework allows the assessment of a variety of different energy harvesting technologies and perceptive tasks. In this paper, two representative scenarios are used to parameterise the model with specific efficiency and energy abundance figures. Simulation results indicate that the integration of intelligent power management with traditional sensor management processes can significantly increase operational endurance and, in some cases, simultaneously improve surveillance or tracking performance. Furthermore, the framework is used to assess the potential impact of energy harvesting technologies at various efficiency levels. This provides important insight into the potential benefits that intelligent power management can offer in relation to improving system performance and reducing the dependency on fossil fuels and logistical support.

7692-78, Poster Session

On the reliability of collaboration and coordination of unmanned vehicle network

A. M. Dixit, K. Saab, H. Singh, Wayne State Univ. (United States); G. R. Gerhart, U.S. Army Tank-Automotive Research, Development and Engineering Ctr. (United States)

There has been increasing interest during the last several years in the development of unmanned vehicles. A large number of such vehicles are soon going to play a major role in defense and security in a battlefield environment. The objective of the present paper is to ascertain the overall reliability of a large number of unmanned vehicles in the battlefield. The problem is broken up into two parts, collaboration and coordination of unmanned vehicle network. Collaboration is the communication between a set of unmanned vehicles which are likely to move in a group. Coordination is the movement of one group of unmanned vehicle from one source node to another destination node keeping in view the obstacles and the difficulties in the movement of path. This paper utilizes the existing well known techniques in the literature for finding the node and terminal reliabilities. These are further used to obtain the system

reliability of unmanned vehicle network. Fuzzy rules based on experience from past are suggested for the implementations. A simulation of ground vehicle network having node, branch and terminal simulations is given. It is hoped that the technique proposed here will prove useful in developing future approaches for ascertaining overall reliability of unmanned ground networks.

7692-44, Session 9

Life after Army FCS: an Army family of ground robotic systems

D. G. Knichel, Maneuver Support Ctr. (United States)

Until recently, the Army Future Combat System (FCS) was the future of Army ground robotics but new missions, threats, and realities has caused the Army to re-think the future of Army ground robotics.

The result is a new direction for Army ground robotics that includes modernizing the current Infantry, Heavy, and Stryker Brigade Combat Teams (BCT) with FCS spinout systems. In addition and I believe more importantly, also developing a family of Army common ground robotics platforms hallmarked by interoperability, standardization, and common sub components whenever possible.

MANSCEN has historically been a leader in Army ground robotics from the Mini Flail and Panther teleoperated tank in the 1990s to the Army's first fielded semi autonomous ground robot, the Mobile Detection Response System (MDARS) in 2006. The path ahead for the Army Maneuver Support Center includes collaborative air and ground robotics, robotic IED defeat and route protection robots, robotic decontamination, and teams of ground robots delivering and deploying tactical payloads such as assault bridging.

To achieve a common family of ground robots interoperability the approach will share the Army Unmanned Aircraft Systems (UAS) standards such as STANAG 4545, 4609, and 4575 as well as rely on standards from the Joint Technical Architecture (JTA), Joint Architecture Unmanned Systems (JAUS) and industry standards such as the Automotive Consortia Standards ISO 11898 Controller Area Network (CAN) and LIN (Local Interconnect Network).

7692-45, Session 9

Integration of a high degree of freedom robotic manipulator on an unmanned ground vehicle

J. Giesbrecht, B. Fairbrother, Defence Research and Development Canada (Canada)

The Multi-Agent Tactical Sentry (MATS) Unmanned Ground Vehicle, developed at Defence R&D Canada - Suffield, has been in service with the Canadian Forces for 5 years. This tele-operated robotic wheeled vehicle provides capability to do point detection of CBRN agents. Due to experience with soldiers using the vehicle in various trial scenarios, it has become obvious that a manipulator capability would greatly enhance the vehicle's utility. This paper reports on the technical components of this development, as well as a number of experiments undertaken to do everyday tasks from a remote wheeled platform with a manipulator arm. These experiments involve investigating suspicious scenes by picking up objects, opening vehicle and building doors and recording video from various points of view.

7692-46, Session 9

Convoy active safety technologies warfighter experiment III

E. W. Schoenherr, U.S. Army Tank-automotive and Armaments Command (United States); B. L. Theisen, U.S. Army Tank-

Automotive Research, Development and Engineering Ctr. (United States)

The operational ability to project and sustain forces in distant, anti-access and area denial environments poses new challenges for combatant commanders. One of the new challenges is the ability to conduct sustainment operations at operationally feasible times and places on the battlefield. Combatant commanders require a sustainment system that is agile, versatile, and survivable throughout the range of military operations and across the spectrum of conflict. A key component of conducting responsive, operationally feasible sustainment operations is the ability to conduct sustainment convoys. The ability to conduct sustainment convoys in a variety of hostile environments require force protection measures that address the enemy threat and protect the Soldier. One cost effective, technically feasible method of increasing the force protection for sustainment convoys is the use of robotic follower technology and autonomous navigation. The Convoy Active Safety Technologies (CAST) system is a driver assist, convoy autopilot technology aimed to address these issues. The CAST Warfigher Experiment III, being held at Fort Hood, TX in 2010, will continue analysis of the utility of this vehicle following technology not only in measures of system integrity and performance vs. manual driving, but also the physiological effects on the operators themselves. This includes EEG data collection for cognition and fatigue measurement, eye tracking, roadside threat response time analysis, and vehicle convoy formation maintenance and performance measures. This paper will detail this experiment's methodology and analysis. Results will be presented at the SPIE Defense & Security 2010 symposium.

7692-47, Session 9

Miniature unmanned ground vehicle development for CIED in Afghanistan

D. R. Erickson, Defence Research and Development Canada (Canada)

This paper describes Defence Research & Development Canada's (DRDC) miniature unmanned ground vehicle (MUGV) project undertaken at DRDC Suffield as a response to the current IED threat. The roadside bomb has become a significant weapon in the arsenal of non-state actors conducting asymmetric warfare and it is anticipated to remain prominent beyond current conflicts. A significant characteristic of this threat is the time-varying nature of the devices, tactics, and techniques. This project delivered a rapid response EOD/IEDD vehicle system to Afghanistan against the changing IED threat and operational needs.

The approach undertaken in this work involved a soldier-scientist team aimed at improving and evolving the system capabilities in real time starting with operation evaluation feedback and ending with evolved prototype designs delivered. The design was envisioned to undergo spiral re-engineering based on the updated needs for platform performance and payloads to face new devices. This work hightlights the challenges and opportunities involved in an evolutionary acceptance strategy for human-robot teaming, where soldier input in the design process can increase the trust and understanding of a proposed prototype system. This paper outlines the current results, future work, and possible applications of this system.

7692-48, Session 9

An overview of the 2009 Fort Hood robotics rodeo

S. Norberg, U.S. Army Tank-automotive and Armaments Command (United States)

The Robotics Rodeo held from 31 August to 3 September 2009 at Fort Hood, Texas, had three stated goals: educate key decision makers and align the robotics industry; educate Soldiers and developers; and perform a live market survey of the current state of technologies to encourage the

development of robotic systems to support operational needs.

Both events that comprised the Robotics Rodeo, the extravaganza and the robotic technology observation, demonstration and discussion (RTOD2) addressed these stated goals. The extravaganza was designed to foster interaction between the vendors and the visitors who included the media, Soldiers, others in the robotics industry and key decision makers. The RTOD2 allowed the vendors a more private and focused interaction with the subject matter experts teams, this was the forum for the vendors to demonstrate their robotic systems that supported the III Corps operational needs statements that are focused on route clearance, convoy operations, persistent stare, and robotic wingman.

While the goals of the rodeo were achieved, the underlying success from the event is development a new business model that is focused on collapsing the current model to get technologies into the hands of our warfighters quicker. This new model takes the real time data collection from the rodeo, the Warfighter Needs from TRADOC, the emerging requirements from our current engagements, and assistance from industry partners to develop a future Army strategy for the rapid fielding of unmanned systems technologies.

7692-49, Session 9

Semi-autonomous MAV/UGV for dismounted urban operations

M. Trentini, B. H. Beckman, Defence Research and Development Canada (Canada)

Dismounted soldiers are clearly at the centre of modern asymmetric conflicts and unmanned systems of the future will play important roles in their support. Moreover, the nature of modern asymmetric conflicts requires dismounted soldiers to operate in urban environments with challenges of communication and limited situational awareness. To improve the situational awareness of dismounted soldier in complex urban environments a MAV rotorcraft and UGV will assist in dismounted operations. The capabilities that will be provided to the MAV rotorcraft include high speed maneovres through urban terrain, over-the-horizon and loss of communications operations, and/or low altitude over-watch of dismounted units. This information is shared with both the dismounted soldiers and UGV. The man-sized, man-mobile UGV operates in close support to dismounted soldiers to provide a payload carrying capacity. Some of the possible payloads include CBRNE detection systems for first point of contact. These unmanned systems are intended to increase situational awareness in urban environments and can be used to call upon nearby forces to react swiftly by providing acquired information to concentrate impact where required.

7692-50, Session 9

Fractionated multirobotics: a hierarchical approach

G. A. Konesky, K-Plasma Ltd. (United States)

Increasingly, the term "divide and conquer" can be applied to robotic situations where the advantages of a large array of smaller robotic devices with distributed capability, are compared to one large ponderous device with concentrated capability. Advantages include fault tolerance, simultaneous distributed sensing over a larger area, and a capacity for self-rescue by cooperative interaction. Typically, the multi-robotic "swarm" consists of individual robotic agents that are identical, limiting mission scope. By fractionating, or subdividing specialized capability within the swarm, cooperative interaction can be subdivided into tasks that can be arranged in a hierarchical order, significantly expanding overall mission capability, while retaining the advantages of a multi-robotic approach. This design paradigm was applied to a test prototype consisting of a large carrier robotic vehicle which transports an array of smaller specialized robotic vehicles, all of which are teleoperated. At a given site, the small specialized vehicles are deployed, interact cooperatively to accomplish a specific mission, are then collected by the

large carrier vehicle, and transported to the next site for the next mission. Typical examples of small vehicle specialization include hyperspectral imaging, sample acquisition and preparation, sample analysis, and sample archiving. Each of these individual modes of specialization can be conducted sequentially, cooperatively, and in parallel. The large carrier vehicle acts as a teleoperation relay for the smaller vehicles, as well as provide power recharge capability. Details of prototype construction and operation are discussed.

7692-51, Session 10

Human leader and robot follower team: correcting leader's position from follower's heading

J. Borenstein, D. L. Thomas, Univ. of Michigan (United States); B. Sights, Space and Naval Warfare Systems Ctr. Pacific (United States)

This paper presents a method for correcting the inaccurate position estimates of an IMU-based dead-reckoning system on a human leader by means of the accurate position estimates of a robot follower. While the human leader walks, the dead-reckoning system wirelessly streams the leader's position estimates to the robot follower. The robot follows the human based on the leader's streaming position data (line-of-sight is not required), while the robot also streams its own high-precision position data to the leader. The paper describes our "RoFo" algorithm that corrects the leader's heading errors, despite some temporal and spatial differences in the two paths.

In practice, RoFo estimates the drift of the leader's z-axis gyro by comparing leader heading to robot heading when the robot passes near a point that the leader passed earlier. RoFo then issues a small correction to the leader's gyro output. Performing the comparison and issuing small corrections over many consecutive intervals is highly effective in estimating drift, even though momentarily the robot and leader headings may differ substantially (e.g., because of local obstacle maneuvers or differences in turning corners).

The paper presents detailed experimental results that show how RoFo almost completely eliminates the leaders' heading errors in long walks that would otherwise produce heading errors of many tens of degrees.

While our method was developed specifically for a human leader/robot follower constellation, we believe it can easily be applied to other leader-follower constellations, including the special case of convoys.

7692-52, Session 10

A hybrid approach to indoor geo-location combining visual navigation and WiFi localization techniques

J. C. McBride, Charles River Analytics, Inc. (United States); K. Pahlavan, Worcester Polytechnic Institute (United States); M. S. Snorrason, Charles River Analytics, Inc. (United States)

Self-localization is an important capability for both manned and unmanned systems, especially in complex and highly structured urban environments such as building interiors. While GPS is often unavailable or unreliable in these scenarios, techniques that leverage signals of opportunity such as IEEE 802.11 (WiFi) offer a promising alternative. However, accuracy is comparable to GPS and generally not sufficient for navigating narrow and enclosed spaces. Vision-based navigation techniques are better suited to this task, providing accurate sensing of the local scene from one or more video cameras, but they are also highly dependent on scene texture, scene structure and visual persistence over time. Adverse imaging conditions can make visual navigation unreliable over extended distances. To achieve a robust and accurate self-localization capability, we present a hybrid approach which combines signal-based and vision-based localization techniques. For signal-based localization, we recover a rough estimate of global position based on

the received signal strength (RSS) of multiple WiFi access points. For vision-based navigation, we employ a standard simultaneous localization and mapping (SLAM) technique which uses motion estimates and scene observations from a moving camera to recover position within that scene. A particle filter provides a probabilistic model of the solution based on measurements, observations and expected errors. Using this framework, we combine SLAM position estimates with WiFi position estimates to arrive at a more accurate and robust result even under difficult imaging conditions. Results are presented from experiments using a mobile robot and stereo camera navigating inside a building with multiple WiFi access points.

7692-53, Session 10

Robotic-mounted detection system: robotics for route clearance

J. E. Hutchison III, G. A. Klager, U.S. Army Night Vision & Electronic Sensors Directorate (United States); E. D. McCoy, U.S. Dept. of Defense (United States)

Robotic Mounted Detection System (RMDS) is a government program to enable robotic control of a Husky route clearance vehicle with a mine detection sensor payload. The goal is for the operator to control the Husky and mine detection sensor from another vehicle. This program will provide the user with standard tele-operation control of the vehicle as well as semi-autonomous modes including cruise control, precision waypoint navigation with operator error correction and a visual mode allowing the operator to enter waypoints in the current video feed. The use of autonomy will be tailored to give the operator maximum control of the robotic vehicle's path while minimizing the effort required to maintain the desired route. Autonomous alterations of the path would conflict with the goal of route clearance, so waypoint navigation will allow the operator to supply offsets to counteract location errors. While following a waypoint path, the Husky will be capable of controlling its speed to maintain an operator specified distance from the control vehicle. Obstacle avoidance will be limited to protecting the mine detection sensor, leaving any decision to leave the path up to the operator. Video will be the primary navigational sensor feed to the operator, who will use an augmented steering wheel controller and computer display to control the Husky. A LADAR system will be used to detect obstacles that could damage the mine sensor and to maintain the optimal sensor orientation while the vehicle is moving. Practical issues and lessons learned during integration will be presented.

7692-54, Session 10

Structure mapping for unmanned systems navigation and missions planning

J. Morrison, W. Calcutt, M. Reese, J. Williams, McQ, Inc. (United States); G. J. Roehrich, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

McQ developed for the U.S. Army Armament Research, Development and Engineering Center (ARDEC) an acoustic and infrared measurement, node localization, and building characterization prototype system. The system is designed for both manned and unmanned use to develop greater situational awareness through the exploration of unknown structures and relay of mapping data through ARDEC's Firestorm network. When employed by personnel, the system will map a structure with minimal user intervention and supply floor plans and current location when needed. Data can be immediately relayed to personnel both inside and outside of the building for up-to-date maps and user location. This research covers ultrasonic and infrared ranging sensor performance, GPS-denied positioning solutions, sensor data fusion, and mapping algorithms. Applications of McQ's structure mapping system also include first responder mapping and positioning. Maps generated by the system are useful for both real-time operations and future missions planning. McQ will present development methodology and performance.

A visual odometry method based on the SwissRanger SR-4000

C. Ye, Univ. of Arkansas at Little Rock (United States); M. H. Bruch, Space and Naval Warfare Systems Ctr. Pacific (United States)

This paper presents a robot pose estimation method based on a new 3-D imaging sensor the SwissRanger SR4000. The pose of a robot here refers to its Euler angles (i.e., roll, pitch and yaw angles) and 3D location (i.e., X, Y, Z coordinates). The proposed method shares the similar operating principle of the Visual Odometry (VO) [1]. Most of the existing VO methods are based on stereovision that has the following disadvantages: (1) The depth information of a 3-D point is determined by its image disparity. This requires a correct pixel-correspondence (between the left and right cameras' images) that is not always available. (2) The accuracy of depth measurement quadratically drops with the increasing true depth. This usually restricts the data usefulness to be within a range of 2 meters. In other words, a stereovision-based VO method may fail in a less-featured environment or may incur unacceptable pose estimation accuracy. The proposed method overcomes these disadvantages by utilizing the SR4000's capability of simultaneously producing a range image and an intensity image of its operating environment. In its current implementation, the method first detects the Scale-Invariant Transform Feature (SIFT) in an intensity image of the SR4000 and match these features to the SIFT features of another image captured by the sensor at a different view point. The feature matching process rejects unlikely matches determined by a measure based on distances between features [1]. It can not completely remove ambiguous matches. The problem is resolved by a RANSAC approach implemented on the 3-D data points associated with the features. The RANSAC approach randomly selects four matched features and computes the associated transformation matrix. Then a vote is casted on the transformation matrix among all data points associated with the SIFT features. This process is repeated with sufficient number of time and the transformation with the largest number of votes is selected as the estimated transformation that eventually determines the robot pose. The RANSAC method finds the sub-optimal estimate of the robot pose and removes the incorrect feature matches simultaneously. Figure 1 depicts the result of a case study where the camera tilts up 9 degrees. Figure 1a and 1b show the matched features before and after the RANSAC method, respectively. Since the SR4000 has a consistent measurement accuracy (+/- 1 cm) in its operating range (0.3~5 meters), a better pose estimation accuracy (compared with stereovision-based method) may be achieved. In this particular experiment, the mean value of the measured pitch angle is 9.03 degree and the standard deviation is 0.59 degree. In this work, we will also present a thorough characterization study on the proposed method's measurement accuracy.

Figure 1 A case study in an office environment: Two intensity images were acquired by the SR4000 at two view points (pitch angle: 10 degrees). Each green line shows a pair of matched features.

Reference

[1] Y. Cheng, M. W. Maimone, and L. Matthies, "Visual odometry on the Mars exploration rovers - a tool to ensure accurate driving and science imaging," IEEE Robotics and Automation Magazine, vol. 13, no. 2. pp. 54-62, 2006.

[2] D. G. Lowe, "Distinctive image features from scale-invariant keypoints," International Journal of Computer Vision, vol. 2, no. 60, pp. 91-110, 2004.

Dexterous industrial robotics for responsive defense applications

C. Kapoor, Agile Planet, Inc. (United States); E. Nieves, Motoman Inc. (United States)

Industrial robotics has a 40 year history of evolutionary improvement that has led to the development of highly precise machines with an upwards of an 80,000-hour life. These systems have had low payload to weight ratio with best approaching 1:4. The typical geometries for these arms were restricted to six degrees-of-freedom (DOF) and optimized for speed and reach, which were primarily automotive requirements. Defense robotics has seen growth on two fronts. First are autonomous systems, which are still under development, and second are teleoperated robotic systems for reconnaissance and Explosive Ordinance Disposal. These systems are characterized by operator in the loop control with the teleoperation of the robotic manipulator being a significant challenge. These challenges stem from lack of system dexterity, limitation in terms of number of robot arms, the operator interface, and the lack of autonomous tasking. Various research labs and small companies are addressing these problems through the development of high DOF robot arms that are lighter, slimmer, and offer open real-time integration interfaces that can be coupled with innovative operator interfaces. These efforts have rarely leveraged proven industrial technology and innovations in robot motion planning. This talk will show how innovations in industrial robotics technology and motion planning software provide a solid foundation for building highly dexterous robotic systems that are cost-effective and can perform reliably in the challenging battlefield environment.

Mobile robot grid map building with laser scanner

H. Cao, H. Sun, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

A method of mobile robot grid map building was proposed for the issue of mobile robot simultaneous localization and mapping (SLAM) in an unstructured environment without a priori map.

The location of mobile robot was estimated through Odometry. In a long-distance, cumulative odometry error was quite considerable and, therefore, this location should be amended by laser scanner measurement data.

The unstructured environment was explored with a 2-D laser scanner, SICK LMS 200, installed on a mobile robot. The scanner can measure ranges up to 8m with 15mm system error and 5mm standard deviation. We limited our interest to the 1° resolution setting, where a full scan of 180° produces 181 measured range values.

An improved Dempster-Shafer evidence theory was used to fuse laser scanner information. The problem that Dempster-Shafer evidence theory can't be applied to information fusion under certain circumstances and the matter that Dempster-Shafer evidence theory has counter-intuitive behaviors in some cases were discussed. An approximate process algorithm was advanced to avoid above problems and improve Dempster-Shafer evidence theory.

Recently, Rao-Blackwellized particle filters (RBPF) have been introduced as an effective means for SLAM problem. This approach uses a particle filter in which each particle carries an individual map of the environment. Therefore, a key question is how to reduce the number of particles. In this paper, an efficient RBRF which can reduce particle number was used for SLAM.

Finally, a 2-D grid map was built. Simulation result shows that this method is appropriate for unstructured environment grid map building.

Conference 7693: Unattended Ground, Sea, and Air Sensor Technologies and Applications XII

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7693-01, Session 1

Small form factor two-color semiconductor laser infrared fiber-coupled illuminator

J. C. Connolly, Innovative Photonic Solutions (United States)

We will report our results for a two-color semiconductor laser infrared illuminator containing laser sources at 2.2 µm and 4.6 µm that combines the optical output onto a single optical fiber. The illuminator operates at room temperature from 1% to 100% duty cycle and both modulation and output power level are controlled by TTL signals. The illuminator total volume (including thermal management and electronic controls) is about 0.1 ft3 and the total weight of the system is <5 lbs. The total optical power from the system is > 2 watts and each laser wavelength can be operated independently of one another. We will discuss both the illuminator performance as well as illuminator thermal management.

7693-02, Session 1

Engineering rare-earth-doped heavy metal oxide glasses and glass-ceramic hosts for 2-5 µm lasers

A. Jha, B. D. O. Richards, Univ. of Leeds (United Kingdom); T. Manzur, Naval Undersea Warfare Ctr. (United States)

The electronic states in trivalent rare-earth ions offer an excellent opportunity for designing efficient fibre and bulk lasers for atmospheric remote sensing and LIDAR technology. The first part of this review article focusses on engineering fibres and bulk glasses for 2-5 µm wavelength, especially for maximizing the slope efficiency for lasers in the 3-5 µm range, using 2 µm CW and pulsed sources. The methods for reducing background loss in fibres and bulk glass materials are discussed.

In the 2nd part of the review we compare the slope efficiencies of Tm3+ and Tm3+-Ho3+ doped glasses and fibres for 1950-2080 nm lasers using a range of pumping schemes in tellurite and germanium oxide hosts. We also explain the importance of choosing 1950-2080 nm tunable laser as a pump source for stimulated emission at longer wavelengths. For such pumping scheme, we examine the spectroscopy of significant rare-earth ions in tellurium oxide and germanium oxide glasses and compare them with the properties of sulphide and fluoride glasses, especially for 3-4.5 µm lasers. A method for power scaling using the fibre and bulk structures is proposed.

7693-03, Session 1

A focal mini-scan-mirror beam steering with MWIR quantum cascade laser for next-generation MANPAD countermeasures

D. Kane, Areté Associates (United States)

The requirement for a low-cost, high reliability, light weight, and efficient Aircraft Self-Protection Suite, that can detect, disrupt, and defeat current and next-generation passive IR and command-guided MANPAD threats for small rotary aircraft such as the AH-60 and AH-1 remain unmet. This program is demonstrating the Mini-Scan-Mirror (MSM) in an Afocal MSM Beam Steering (AMBS) configuration combined with an MWIR Quantum Cascade laser. These are enabling technologies that could transform the existing Airborne Survivability Equipment (ASE) architecture. Currently, each threat countermeasure system has proprietary interfaces and system architectures. The MSM allows for an architecture that can detect and counter multiple threats with an open architecture

system. The AMBS technology has excellent potential to be used in the following ASE applications: IR countermeasures, hostile fire indication detection and geolocation, optical augmentation for preemptive optical threat geolocation, laser warning sensor, and eye-safe laser dazzle countermeasure.

The MSM Pointer Tracker program was initiated as a technology demonstration program with the ultimate objective of replacing the current turret-based Pointer Trackers used for IRCM. Anticipated benefits include significant reductions in weight, power consumption, external profile and cost and reliability. Anticipated benefits of a MSM Pointer Tracker / QC MWIR laser system based on anticipated performance for a production configuration include: Weight (MSM Pointer Tracker + QC MWIR Laser) ~ 24 pounds, power consumption of 200 W w/o laser, external profile volume < 27 in3 (total volume < 1,350 in3), fast scan performance (10 ms-level) of 180° point-to-point step response, and high reliability of 5000+ hr.

7693-04, Session 1

Implementation of a monolithic gas detector

A. J. Davis, Naval Undersea Warfare Ctr. (United States); O. J. Gregory, G. Fischer, Univ. of Rhode Island (United States)

A monolithic gas sensor is being designed for the purpose of detecting specific gases using metal oxide catalysis. The chip will be fabricated in a standard CMOS process via MOSIS. The glass and metal layers will be removed in order to access the poly-Silicon layers for post-fabrication processing. The catalyst will then be deposited onto the poly-Silicon layers using chemical vapor deposition (CVD). The chip will contain circuitry to provide specific gas-detection and IR imaging of the micro-heater will also be performed. Experimental results will be reported.

7693-05, Session 1

High-power, broadband mid-infrared supercontinuum fiber laser

M. N. Islam, Univ. of Michigan (United States)

A Mid-InfraRed FIber Laser (MIRFIL) has been developed that generates super-continuum covering the spectral range from 0.8 to 4.5 microns with a time-averaged power as high as 10.5W. A number of advances have been made in the MIRFIL platform recently, including expanding the long wavelength edge of the supercontinuum, increasing the supercontinuum generation efficiency, modulating the MIRFIL output, and further increasing the power from the laser.

Some of the applications using the super-continuum laser will be described in defense, homeland security and healthcare. For example, the MIRFIL is being investigated to protect helicopters from heat seeking missiles using directed infrared counter-measures. Using spectral fingerprinting, the MIRFIL can also be used for remote, non-contact detection of explosives and firearms. In addition, the MIRFIL is being applied in dermatology and cardiology to remove fat or adipose tissue. In particular, the MIRFIL can be a platform selective laser ablation of fatty tissue without damaging normal protein or smooth muscle tissue.

7693-06, Session 1

Distributed optical microsensors for hydrogen leak detection and related applications

S. R. Hunter, Oak Ridge National Lab. (United States); J. R.

Patton, M. J. Sepaniak, The Univ. of Tennessee (United States); P.
G. C. Datskos, B. Smith, Oak Ridge National Lab. (United States)

This paper will report on the recent advances made to develop optically
interrogated microsensor based chemical sensors with specific
application to hydrogen vapor sensing and leak detection in the hydrogen
economy. We have developed functionalized polymer-film and palladium/
silver alloy coated microcantilever arrays with nanomechanical sensing.
The uniqueness of our approach is in the use of independent component
analysis (ICA) and the classification techniques of neural networks to
analyze the signals produced by an array of microcantilever sensors.
This analysis identifies and quantifies the amount of hydrogen and
other trace gases physisorbed on the arrays. Selectivity is achieved
by using arrays of functionalized sensors with a moderate distribution
of specificity among the sensing elements. The device consists of an
array of beam-shaped transducers with molecular recognition phases
(MRPs) applied to one surface of the transducers. Bending moments
on the individual transducers can be detected by illuminating them with
a laser or an LED and then reading the reflected light with an optical
position sensitive detector (PSD) such as a CCD. Judicious selection
of MRPs for the array provides multiple isolated interaction surfaces for
sensing the environment. When a particular chemical agent binds to a
transducer, the effective surface stresses of its modified and uncoated
sides change unequally and the transducer begins to bend. The
extent of bending depends upon the specific interactions between the
microcantilever's MRP and the analyte. Thus, the readout of a multi-
MRP array is a complex multi-dimensional signal that can be analyzed to
deconvolve a multicomponent gas mixture. The use of this sensing and
analysis technique in unattended networked arrays of sensors for various
monitoring and surveillance applications will be discussed.

7693-07, Session 1

Chalcogenide fiber for mid-infrared transmission and generation of laser source

F. Chenard, IRFlex Corp. (United States)

Every chemical and molecule has its own spectral absorption features.
The spectral absorption lines in the mid-infrared (4-10 micron) are
much stronger and more detailed than other parts of the spectrum.
The mid-infrared absorption lines are often referred to as the "chemical
fingerprint" of the molecule or the chemical. This specific mid-infrared
signature is used for chemical sensing, medical diagnostics, industrial
process control, pollution monitoring, explosive detection, and real-time
combustion controls. The advent of advanced low-loss mid-infrared
chalcogenide fibers enables remote sensing capabilities and greater
compactness, flexibility, efficiency and reliability than alternative bulky
sensing solutions. Also the mid-infrared fiber-optic sensor is the 1st
choice for sensing applications characterized by minimal space, adverse
environment, or electromagnetic interference. This paper describes
the latest results on high transmission chalcogenide fiber in the 1-10
micron range. Also chalcogenide glass fiber is the only mid-infrared fiber
technology to transmit from 1 to 10 micron and suitable for mid-infrared
remote sensing and sensors networks. Furthermore chalcogenide glass
fiber is better than silica and fluoride fibers to demonstrate rare-earth
doped fiber laser and supercontinuum sources in the mid-infrared. We
will show the latest progress on the fiber laser at around 4.5 micron. We
will also discuss the design of an innovative chalcogenide fiber to enable
supercontinuum generation in the mid-infrared.

7693-08, Session 1

Compact parametric THz sources based on monolithic pulsed fiber lasers in the C-band

W. Shi, A. Chavez-Pirson, NP Photonics, Inc. (United States)

In this paper, we report our recent achievements in high power single-
frequency pulsed fiber lasers in the C-band and fiber laser based THz
generation. In our monolithic pulsed fiber laser system based on MOPA

configuration, the peak power can reach more than 100 kW when the
repetition rate is 10 kHz and the pulse width 2.5 ns. This result is based
on a new large core single mode highly Er/Yb co-doped phosphate fiber
with core size of 25 mm. This is the highest peak power achieved so
far for fiber laser pulses with transform-limited linewidth. An arbitrary
waveform generator (AWG) is used to pre-shape the optical pulse shapes
by driving an electro-optic modulator (EOM) to directly chop a CW
single-frequency fiber laser - producing pulses shaped to avoid dynamic
saturation in the cascade of fiber amplifiers. The single-pass generated
THz peak power can reach 0.12 W based on difference frequency
generation (DFG) of 1550 nm and 1538 nm pulses in a GaSe crystal.
Moreover, the nanosecond pulsed fiber lasers have been successfully
intensified by an external cavity, and the external cavity enhanced THz
generation has been observed for the first time using single-frequency
pulsed fiber lasers. We have obtained THz power enhancement factor of
7.7 for the external cavity enhanced difference-frequency THz generation.

7693-09, Session 2

Inexpensive wide-angle lenses for unattended imagery

W. S. Weiss, Naval Undersea Warfare Ctr. (United States)

In the realm of inexpensive, low power, and even expendable
unattended sensors, complex camera systems that include pan and
zoom mechanisms have the disadvantage of being expensive, energy
consumers, and not necessarily expendable. This paper discusses
the potential use of inexpensive, light weight, wide angle lenses to
capture full panoramic views, eliminating the need for pan and zoom
mechanisms.

When airborne, a wide angle lens could provide a downward looking
full hemispherical view of the land or the sea. When ground based or
seaborne, pointing straight up, it could provide an upward looking full
hemispherical view of the sky. The images from wide angle lenses could
be throughput sophisticated algorithms that search for targets, alert end
users, and provide full wrap around situational awareness in all directions.

7693-10, Session 2

Photomechanical thermal imager for unattended sensing

J. P. Salerno, Agiltron, Inc. (United States)

Photomechanical thermal imaging utilizes a passive infrared sensor
array in conjunction with a low-power, off-the-shelf CMOS visible light
sensor. This low size, power and weight (SWaP) thermal camera is
inherently suited to unattended sensing for ground, vehicle, and aircraft
applications. Inclusion of the visible light sensor in the thermal camera
provides the option for optically fused thermal and visible imaging. The
operating principles of the imager and its unique attributes related to
unattended sensing will be presented, as well as current and potential
performance parameters.

7693-11, Session 2

Next-generation nanostructure based EO/ IR focal plane arrays for unattended ground sensor applications

A. K. Sood, Magnolia Optical Technologies, Inc. (United States);
T. Manzur, Naval Undersea Warfare Ctr. (United States)

Next Generation EO/IR focal plane arrays using nanostructure materials
are being developed for a variety of Defense Applications including
Unattended Ground Sensor Applications. Several different nanomaterials
are being evaluated for these applications. These include ZnO nanowires
that have demonstrated large signal to noise ratio as a wide band gap

nanostructure material in the UV band. Similarly, the work is under way using Carbon Nanotubes (CNT) for a high speed detector and focal plane array as bolometer for IR bands of interest, which can be implemented for the unattended ground sensor applications.

In this paper, we will discuss the sensor design and model predicting performance of an EO/IR focal plane array that can cover the UV to IR bands of interest. The model can provide a robust means for comparing performance of the EO/IR FPA's and Sensors that can operate in the UV, Visible-NIR (0.4-1.8µ), SWIR (2.0-2.5µ), MWIR (3-5µ), and LWIR bands (8-14µ). This model can be used as a tool for predicting performance of nanostructure arrays under development. We will also discuss our results on growth and characterization of ZnO nanowires and CNT's for the next generation sensor applications.

7693-12, Session 2

MWIR photodetector based on laser-doped silicon carbide

G. Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. Kar, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

MWIR photon detector in the mid-infrared wavelength (3 - 6 µm) range is developed using crystalline silicon carbide substrates. SiC, which is a wideband gap semiconductor, is laser-doped to create a dopant energy level corresponding to a quantum of energy for the required operating wavelength of the detector. The photons of the objects in the field of view excite the electrons of the detector, leading to changes in the refractive index. This change in the optical property of the detector can be measured remotely with a laser beam, such as a He-Ne laser beam of wavelength 632.8 nm, which makes it a wireless detector. While many IR detectors require cryogenic cooling (77 K) to suppress thermal generation-recombination processes in order to operate with good detectivity, the SiC-based detector can operate at room temperature with excellent performance. An n-type 4H- SiC substrate has been doped with Ga by a laser doping technique to create a detector element for the MWIR wavelength of 4.21 µm corresponding to the photon energy 0.30 eV. The dopant energy level is confirmed by optical absorption measurements. The change in the refractive index is studied as a function of absorbed irradiance on the detector and the detectivity is calculated to be 3.913×10^{14} cm(Hz)1/2/W. Other dopants can be incorporated into the 4H-SiC substrate to produce MWIR room temperature detectors for different wavelengths in the MWIR range.

7693-13, Session 2

Optical turbulence modeling

S. Jordan, T. Manzur, Naval Undersea Warfare Ctr. (United States)

Accurate spatial and temporal resolution of the turbulent structure surrounding thin cylinders at zero to low angles-of-incidence (AOI) is paramount to design considerations of cabling systems in the US Navy. A good example is the tether of a towed UUV. Unfortunately, our understanding of the turbulent properties and near-wall forcing is still at large. The scope of the present paper centers on the temporal and spatial resolution of statistically symmetric, asymmetric and wake-like turbulent structures of straight and modestly curved circular cylinders by the large-eddy simulation (LES) methodology. LES resolution of the outer turbulent structure of the thin cylinder bears no resemblance to the content of the flat plate at comparable Reynolds numbers. Furthermore, spectral observations of the near-wall pressure show complete dissimilarity under Strouhal scaling.

7693-14, Session 2

Optimized aspect ratio high-resolution sensor for surveillance

J. Sheets, K. C. Shannon III, Eclipse Energy Systems, Inc. (United States)

A high resolution focal plane sensor array is under development that allows the aspect ratio of the sensor area to be matched to the anticipated target area.

7693-15, Session 2

High-resolution streaming video integrated with UGS systems

M. J. Rohrer, McQ, Inc. (United States)

Imagery has proven to be a valuable complement to Unattended Ground Sensor (UGS) systems. It provides ultimate verification of the nature of detected targets. However, due to the power, bandwidth, and technological limitations inherent to UGS, sacrifices have been made to the imagery portion of such systems. The result is that these systems produce lower resolution images in small quantities. Currently, a high resolution, wireless imaging system is being developed to bring megapixel, streaming video to remote locations to operate in concert with UGS. This paper will provide an overview of how using Wifi radios, new image based Digital Signal Processors (DSP) running advanced target detection algorithms, and high resolution cameras gives the user an opportunity to take high-powered video imagers to areas where power conservation is a necessity.

7693-16, Session 3

Sensor and information fusion for improved hostile fire situational awareness

M. V. Scanlon, W. Ludwig, U.S. Army Research Lab. (United States)

A research-oriented Army Technology Objective (ATO) named Sensor & Information Fusion for Improved Hostile Fire Situational Awareness uniquely focuses on the underpinning technologies to detect and defeat any hostile threat; before, during, and after its occurrence. This is a joint effort led by the Army Research Laboratory, with the Armaments and the Communications & Electronics Research, Development, and Engineering Centers (CERDEC and ARDEC) partners. It addresses distributed sensor fusion and collaborative situational awareness enhancements, focusing on the underpinning technologies to detect/identify potential hostile shooters prior to firing a shot and to detect/classify/locate the firing point of hostile small arms, mortars, rockets, RPGs, and missiles after the first shot. A field experiment conducted addressed not only diverse modality sensor performance and sensor fusion benefits, but gathered useful data to develop and demonstrate the ad hoc networking and dissemination of relevant data and actionable intelligence. Represented at this field experiment were various sensor platforms such as UGS, soldier-worn, manned ground vehicles, UGVs, UAVs, and helicopters. This ATO continues to evaluate applicable technologies to include retro-reflection, UV, IR, visible, glint, LADAR, radar, acoustic, seismic, E-field, narrow-band emission and image processing techniques to detect the threats with very high confidence. Networked fusion of multi-modal data will reduce false alarms and improve actionable intelligence by distributing grid coordinates, detection report features, and imagery of threats.

7693-17, Session 3

Statistical modeling of target signatures for evaluation of UGS performance

G. Prado, SenTech Inc. (United States); D. K. Wilson, U.S. Army Engineer Research and Development Ctr. (United States)

No abstract available

7693-18, Session 3

Parallel spatial algorithms for distributed sensor networks

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

A novel technology will be discussed allowing any distributed and open sets of sensors with local communications to behave as a universal parallel computer solving any problems without central resources. These may relate to overall awareness, distributed pattern recognition, global goal pursuit, and making autonomous decisions. The dynamic sensor networks are governed in Distributed Scenario Language (DSL) allowing us to create compact parallel distributed algorithms navigating and changing physical or virtual spaces using mobile code, stationary and mobile variables, and setting different kinds of command and control. The methodology of creating spatial algorithms in DSL will be revealed, with numerous practical solutions demonstrated in distributed environments controlled by embedded or mobile sensors. The latter include outlining regions of interest (forest fires, flooding, or troops concentration) and setting their metrics; different topological issues of discovered distributed phenomena like connected components, cycles, spanning trees, shortest paths, diameter or radius, weak parts (like articulation points), strong ones (cliques); as well as finding any (sub)structures by spatial matching with spreading graph images (the latter may be conditional and fuzzy). Spatial algorithms can be described in DSL at different levels and their mixtures-from top semantic definitions to detailed infrastructure creation, communication and synchronization, with traditional management routines effectively shifted to distributed execution by communicating interpreters implanted into individual sensors. Details of DSL and its interpreter, which can be implemented in software or hardware, will be revealed. P. Sapaty, "Intelligent management of distributed sensor networks", Proc. SPIE, Vol. 6538, 653812, 2007. www.amazon.com sapaty in books.

7693-19, Session 3

Development of an infrared imaging classifier for UGS

M. T. McCormack, R. D'Agostino, R. L. Steadman, Textron Systems Corp. (United States)

In this paper we show our design process and performance results for the development of an Unattended Ground Sensors (UGS) Automatic Target Recognition (ATR) target classifier using IR imagery. The goal of the project was to develop a basic ATR capability to separate human vs. animal vs. vehicle while optimized for our UGS needs. Our current UGS video capability accurately detects tracks and transmits accurately centered long wave infrared and visible imagery to a base station. The enhanced capability developed would classify and transmit targets of interest to the user and exclude others. A corresponding reduction in the transmission of nuisance targets would enhance the longevity of a remotely placed UGS device by reducing the system power usage. We will show the ATR development process which includes data collection, building a truthed dataset, feature development, classifier training and classifier performance evaluation.

7693-20, Session 3

Learning-based parameter adjustment for robust autonomous freeway driving

J. Wei, J. M. Dolan, Carnegie Mellon Univ. (United States)

For the 2007 DARPA Urban Challenge competition, Carnegie Mellon University's Tartan Racing Team developed primarily rule-based autonomous driving behaviors to perform distance-keeping, lane-changing, and merge operations. We subsequently developed a Prediction- and Cost Function-Based (PCB) algorithm for increased flexibility and performance. Though the use of PCB improves performance, people can still easily tell the difference between the autonomous driving and experienced human driving, since the hand-tooled parameters in PCB do not allow it to perform as smoothly, robustly or in general intelligently as a human driver. In the current paper, we focus on optimizing the PCB algorithm parameters to achieve better performance. The PCB algorithm is first implemented in MATLAB, then human driver data are collected from both a driving simulator and road test. We use a genetic algorithm to optimize the PCB algorithm parameters to emulate an experienced human driver's distance-keeping behavior on freeways. Finally, a comparison road test between the optimized PCB algorithm and a human driver is performed. The results show that learning-based parameter adjustment allows the PCB algorithm to better emulate human driving.

7693-21, Session 3

Planning to fail: using reliability to improve multirobot task allocation

S. B. Stancliff, J. M. Dolan, Carnegie Mellon Univ. (United States)

The reliability of individual robots influences the success of multirobot missions. When one robot fails, others must be retasked to complete the failed robot's tasks. This increases the failure likelihood for these other robots. Existing multirobot task allocation systems consider robot failures only after the fact, via replanning.

In this paper we show that mission performance for a complex multirobot mission can be improved by using knowledge of robot failure rates to inform the initial task allocation.

7693-22, Session 3

Learning a detection map for a network of unattended ground sensors

M. W. Koch, H. D. Nguyen, Sandia National Labs. (United States)

We have developed algorithms to automatically learn a detection map of a deployed sensor field for a virtual presence and extended defense (VPED) system without a-priori knowledge of the local terrain. The VPED system is an unattended network of sensor pods, with each pod containing acoustic and seismic sensors. Each pod has the ability to detect and classify moving targets, but at a limited range. By using a network of pods we can form a virtual perimeter with each pod responsible for a certain section of the perimeter. By fusing together individual detections we can improve the detection range of the network over a single pod's detection range. The site's geography and soil conditions can affect the detection performance of the pods. Thus a network in the field may not have the same performance as a network designed in the lab. To solve this problem we automatically estimate a network's detection performance as it is being constructed.

Our solution is unique in that we estimate the network's detection characteristics as the sensor network is being laid out by a mobile deployment unit (MDU). The MDU will be wearing a differential GPS unit, so the system not only knows when it can detect the MDU, but also the MDU's location. We demonstrate results using simulated and real data collected in complex terrain such as hillsides and ravines. We

will also demonstrate how to handle nonistropic sensor-configurations, geography, and soil conditions. We will also investigate developing sensor maps for other sensor modalities.

7693-23, Session 3

Assessment of a linear pyroelectric array sensor for profile classification

J. B. Brown, S. K. Chari, E. L. Jacobs, The Univ. of Memphis (United States)

A 128-element linear pyroelectric array system was used to capture profiles of potential targets. The array was constructed using a DIAS 128LTI pyroelectric linear array, an F/.086 germanium 58mm lens, and a 18F4550 pic microcontroller for A/D conversion and communication. The pyroelectric array system produces 8-bit imagery of targets moving across the systems field of view and data was collected of both human and animal targets. Data was also collected of human and animal targets using a FLIR A40 long wave infrared camera, which was used to simulate the results of the pyroelectric array system. Binary profiles were created from the real and simulated data. Classification algorithms such as Naïve Bayesian, Linear Discriminant Analysis with Mahalanobis Distance and K-Nearest Neighbors were then trained and tested on the profiles from real data obtained using the pyroelectric array system. The same algorithms were also trained on the profiles for simulated pyroelectric data and tested on the real data. Classification rates from these tests were measured and analyzed.

7693-24, Session 4

Unmanned air systems (UAS) autonomous collision avoidance system (ACAS)

R. T. Hintz, Naval Air Warfare Ctr. Weapons Div. (United States)

No abstract available

7693-25, Session 4

Synthetic aperture radar imaging with motion estimation and autofocus

T. Callaghan, G. C. Papanicolaou, Stanford Univ. (United States); L. Borcea, Rice Univ. (United States)

The main objective of this work is to image moving targets that can be tracked in real time by processing data over sufficiently small sub-apertures. We introduce, from first principles, a synthetic aperture radar imaging (SAR) and motion estimation method that is combined with radar platform trajectory estimation. The method uses both the Wigner transform and ambiguity function of the radar data, properly segmented over small apertures, to derive complementary estimates for the target motion. Using the preliminary motion estimates, the peak of the ambiguity function of the imaging function can be used to estimate relative motion perturbation. This approach produces an iterative approach for parameter estimation for the target motion and autofocus. Only after this has been carried out do we finally construct a high resolution image over the full aperture. The analysis, confirmed by numerical simulation, provides quantitative criteria for implementing the aperture segmentation and parameter estimation process. If there are several targets, stationary or in motion and within view of a given subaperture, they can be used to provide independent estimates of platform trajectory perturbations. This can in turn improve target motion estimation on the ground. Large overlaps of the subapertures increase the robustness of this method by providing more accurate peak selection, motion estimation, and autofocus. However, the computational demands of the method will also increase. We investigate this tradeoff mathematically. X-band persistent surveillance SAR is a specific application of our analysis.

7693-28, Session 5

Unattended monitoring of suspicious behavior for route surveillance

R. M. Schoemaker, R. D. J. Sandbrink, G. P. van Voorthuijsen, TNO Defence, Security and Safety (Netherlands)

A priori information on suspicious behaviour is extremely valuable for countering the IED threat. Suspicious activities along routes during expeditionary operations can be monitored by unattended networks using simple sensing nodes that can gather data for continuous monitoring of daily vehicle activity. Dedicated software yields the necessary intelligence on these activities by filtering suspicious behaviour from anomalous behaviour (including false alarms). Research has started to equip a COTS sensor network with data analysis software. It aims at demonstrating the detection of suspicious behaviour along roads, within a required time span. Three phases are distinguished. First phase is the analysis of traffic flux in a simple scenario with three networks lying at three junctions. The second phase investigates the ability to track and classify one object in this scenario, while the third phase aims to track and classify two or more objects. Findings are presented for phase one.

7693-29, Session 5

Deploying linear fiber-optic seismic sensors for detection of suspicious movements

N. C. Rowe, G. Singh, Naval Postgraduate School (United States)

A relatively new technology for seismic sensors is a kilometer-long buried fiber-optic cable. Active probing can detect echoes due to seismic activity along its length, and estimate their distance; it provides uniform coverage unlike point sensors. We discuss deployment options for such cables and analyze mathematically the tradeoffs between cable length, accuracy of detection, cost of failure, and coverage area. Cables can be curved to accommodate terrain, and this permits deployments along roads but also in parallel lines to cover areas. Parallel lines can be connected to eliminate communications costs, or antennas placed along their lengths, in which case optimal deployment is an interesting combinatorial problem.

Equiangular spirals are the most efficient way to cover terain, but are restricted in their coverage shapes. A key issue for all deployments is the problem of cable failures along the long lengths. We then discuss the problem of finding evidence of suspicious activity in the data based on observed accelerations (changes in speed or direction) as viewed over several time scales. Since the cable can only sense positions along one dimension, we must estimate turns from clues of signal strength or from secondary cables; we discuss the advantages and disadvantages of both. Advance knowledge of the terrain will be helpful in indicating likely positions of turns and loitering.

7693-30, Session 5

The small arms deployable sensor network

M. Mellini, U.S. Army Research, Development and Engineering Command (United States)

The deployment of discrete sensor systems via a small arms system allows for the emplacement of area surveillance networks into urban infrastructure under hostile conditions indigenous to urban warfare, hostage crises, building clearing operations, and military operations on urbanized terrain (MOUT) without placing the Warfighter in harms way. Through the combination of commercial off the shelf (COTS) components, custom commercial hardware, and military high G force hardening technology, the Small Arms Deployable Sensor Network (SmADSNet) allows for a soldier to project a "through the wall" sensing capability at extended ranges with currently issued military hardware in form factors such as the 40mm grenade. SmADSNet is comprised of discrete sensing modalities such as acoustics, magnetics, and passive IR

to detect threats while performing local signal processing and node level fusion in order to relay detection based information from the sensor to the user via a robust, self-forming, self-healing Ad-hoc wireless network. Geo-localization of each deployed node is accomplished through the combination of anchor nodes equipped with GPS located in areas with a sky view as well as the use of multidimensional scaling to resolve the position of nodes in GPS denied areas such as buildings. Commercial enabling technologies allow SmADSNet to be brought from concept to prototype quickly and at low cost giving a disposable and evolvable technology to the user.

7693-31, Session 6

UUV autonomy considerations for extended reach of Naval platforms

P. J. Corriveau, Naval Undersea Warfare Ctr. (United States)

No abstract available

7693-32, Session 6

Advanced distributed maritime sensors

A. Coon, Defense Advanced Research Projects Agency (United States)

No abstract available

7693-33, Session 6

Adding sensor suites to existing commercial maritime vessels in support of homeland security

J. T. Feeley, J. Marino, Rite-Solutions, Inc. (United States)

The US has over 58,000 miles of ocean shoreline, over 5500 hundred miles of Great Lakes shoreline and over 3,500,000 miles of river and small lake shoreline. These waterways are critical to the nation's strategic, economic and societal health. These must be protected from potential terrorist attacks. It is a daunting task for an open society to protect such a large and pervasive asset will still preserving the fundamental rights of its people to enjoy the natural beauty of our waterways.

The US also has a well developed fleet of merchant tugs and barges that enage in day to day commercial activity around the coasts, rivers and lakes of the country . This paper will discuss developing a nationwide mobile sensor network by equiping these barges and tugs with sensor suites that would feed data into a common operations center. The data will be displayed to the first responder community via data streams from Rite View a robust 3D modeling and simulation tool

The data set that will emerge from this will be a rich source of knowledge when looked at through the lens of anlaytics and unsupervised learning algorythms

7693-34, Session 6

Development of semi-fuel cell systems for powering underwater devices

A. M. Cardenas-Valencia, L. Adornato, R. T. Short, L. C. Langebrake, SRI St. Petersburg (United States)

Use of sensor systems in water bodies has applications that range from environmental and oceanographic research, to port and homeland security. In-situ sensing reduces analysis times, increases spatial and temporal density of information, and in the case of chemical sensing,

minimizes sample contamination. Power sources are often the limiting component for further reduction of sensor system size and weight. Although commercial "air-breathing" fuel cells exist, use of this approach in the underwater environment presents challenges. To solve this problem, semi-fuel cells, which supply cathode species, have been under development for about two decades.

We will present recent investigations of metal-anode water-activated galvanic cells that use inexpensive solid oxidizer materials. Solid oxidizers are generally more safely handled than liquid solutions (or gases), have inherently higher current and energy capacity (as they are not dissolved), and, if appropriately packaged, will not degrade over time. Specifically, water-activated Al-cells using inorganic alkali peroxides and solid organic oxidizers (heterocyclic halamines) will be presented. The specific energy, (S.E.), of Al-alkali peroxide was found to be 230 Wh/kg (460 Wh/kg, considering only active materials) in a seven-gram cell. Interestingly, if one increases the cell size (making more area of the catalytic cathode electrode available) the results from a single addition of water in an Al-organic oxidizer cell (weighing ~18 grams) showed an S.E. of about 200 Wh/kg, suggesting that values in excess of 400 Wh/kg could be obtained in a semi-fuel-cell-like system.

7693-35, Session 6

Remote and unattended monitoring of riverine and littoral waters

E. M. Carapezza, DARPA and Univ. of Connecticut (United States)

No abstract available

7693-36, Session 6

An optimization approach to generate robust tradeoffs for the configuration of passive sensor fields against moving targets

T. A. Wettergren, Naval Undersea Warfare Ctr. (United States)

No abstract available

7693-38, Session 7

Time-domain classification of humans using seismic sensors

S. Schumer, U.S. Army Research, Development and Engineering Command (United States)

Techniques are explored for classifying an impulsive set of events in a seismic field as being either human or non human based on information extrapolated from time-domain data of geophones. The methods of classification rely on detecting both the natural cadence as well as the behavior of travel of a human walking compared to animals. As a target is traversing the field of detection, kurtosis is utilized to determine an impulsive event. Real time characteristics are then recorded which can then be used to determine if the target was human. Three unique characteristics are extrapolated from this data: consistency of path, impulse intensity, and footstep frequency. The consistency of path is determined by analyzing the symmetry between the entry of the target to the CPA of the sensor and the CPA of the sensor and the exit of the target. By recreating the time-domain signal by only defining the impulses as simple pulses and ignoring point of noise, the frequency of footstep of the target can be determined, even when multiple targets are present. A cross correlation of the recreated signal will yield an output that can be used to easily determine the most dominant frequency of the observed impulsive event. In conjunction, these methods are capable of classifying humans under certain conditions up to 98% with a varying rate of rejection for different types of animals. The techniques can be easily

integrated to work in conjunction with other modalities for an increase in classifier confidence.

7693-39, Session 7

Range estimation in gunfire localization systems

D. Grasing, B. Ellwood, U.S. Army Research, Development and Engineering Command (United States)

Gunfire detection and localization systems make use of two sounds: The sound of the bullet leaving the barrel of the gun (muzzle blast), and the sound emanating from the bullet when it travels faster than the speed of sound (shockwave). The direction of arrival associated with the muzzle blast will always point in the direction of the shooter. Range could be estimated from the muzzle blast alone however the problem because ill-conditioned at larger ranges. To address this issue additional information obtained from the shockwave (direction and time of arrival relative to the muzzle blast) is utilized in order to obtain range estimates. If the exact weapon type is not known then it is not possible to determine the range. In this paper it is assumed that the actual weapon used is not known but it is know that it is one of several weapons. In general this will lead to multiple solutions all of which equally plausible. By systematically eliminating weapons that could not have produced the observed phenomenon it is possible to reduce the number of weapons needed to consider and use an optimal set of weights for each combination of possible weapons.

7693-40, Session 7

Sensitive optical atomic magnetometer based on nonlinear magneto-optical rotation

D. C. Hovde, Southwest Sciences, Inc. (United States); B. Patton, E. Corsini, Univ. of California, Berkeley (United States); J. M. Higbie, Bucknell Univ. (United States); D. Budker, Univ. of California, Berkeley (United States)

New techniques developed for atomic physics have led to a renewed interest in applications to magnetometry. One such technique, nonlinear magneto-optical rotation (NMOR), exploits alignment coherences among the magnetic sublevels of the ground electronic state to measure magnetic fields with high precision. Using stroboscopic optical pumping via frequency modulation or amplitude modulation spectroscopy, coherence can be created in atoms at Earth's field. An anti-relaxation coating on the walls of the atomic vapor cell results in a long lifetime of up to 0.3 s for the coherence and enables precise measurement of the precession frequency. With proper feedback, the magnetometer can self-oscillate, resulting in accurate tracking and fast time response.

A self-oscillating magnetometer based on AM NMOR in 87Rb has been constructed and tested for airborne detection of submarines. Light is delivered to the magnetometer by polarization-maintaining optical fibers. A pair of photodiodes located near the atomic vapor detect the oscillating polarization rotation from the sample that is the signature of NMOR. Tests of the sensitivity include directly measuring the beat frequency between the magnetometer and a commercial instrument. These tests indicate a sensitivity of at least 10 pT/root Hz, limited in part by magnetic gradient noise. Theoretical analysis indicates that the heading error of our alignment magnetometer should be smaller than that of an orientation-based magnetometer. Rotating the sensor indicates a heading error of less than 1 nT, limited in part by residual magnetism of the sensor.

7693-41, Session 7

MEMS/NEMS based multiferroic uncooled magnetic field sensors and their applications

I. Takeuchi, Univ. of Maryland, College Park (United States); H. Tang, Yale Univ. (United States)

We are developing MEMS/NEMS based ultrasensitive magnetic field sensors utilizing all thin-film multiferroic hybrid heterostructures. Our devices consist of microfabricated all-thin-film based structures. Our approaches take advantage of 1) MEMS based multiferroic thin-film magnetometers we have recently demonstrated for the first time and 2) High Q NEMS based transducers. Several thin-film multiferroic heterostructure geometries are currently being pursued. They include a) magnetostrictive/piezoelectric bilayer and b) magnetostrictive/piezoresistive bilayer geometries with high quality interfaces implemented into micron and submicron sized cantilevers. Key technical challenges lie in large scale fabrication of the MEMS/NEMS based high Q cantilevers and arrays which incorporate robust multiferroic thin film heterostructures and implementing various noise reduction circuits. The low power operation requirement makes these devices attractive compared to other ultrasensitive room temperature detection technologies. By optimizing the circuits and minimizing parasitic capacitance, we hope to achieve the ultimate limit of the multiferroic magnetic field transduction with sensitivity in the pT range and better. The envisioned applications of our devices include weapons detection in various scenarios, soldier health monitoring, biomedical imaging and sensors for automobiles. This project is funded by DARPA and Lockheed Martin.

7693-42, Session 7

Sound source localization by an array of unidirectional microphones

D. Patel, P. Rizzo, Univ. of Pittsburgh (United States)

Targeting people or objects by passive acoustic sensors is of relevant interest in several military and civil applications, spanning from surveillance and patrolling systems to teleconferencing and human-robot interaction. To date methods and patents focused solely on the use of beamforming algorithms to compute the time of arrival of sounds detected by using omnidirectional microphones sparsely deployed. This paper describes the advancements of a novel approach recently proposed by the authors devoted to the localization of ground borne acoustic sources. Pulse features extracted either in the time domain or in the frequency domain are used to identify the direction of the incoming sound. This information is then fed into a semi-analytical algorithm devoted to the identification of the source location. It is demonstrated that an array made of unidirectional microphones can be exploited to detect the position the source. Experimental data obtained in a laboratory environment will be presented. It is believed that this method may pave the road toward a new generation of reduced size sound detectors and localizers.

7693-43, Session 7

A study of the application of infrasound unattended ground sensors (UGS) for border monitoring

D. Norris, S. Stickels, Applied Physical Sciences Corp. (United States)

Infrasound is an attractive tactical sensor modality in border monitoring applications due to its non line-of-sight, long-range detection capability. Anthropomorphic activity, including impulsive events such as explosions and continuous events such as vehicle operation, can be routinely detected over tens of kilometer ranges and beyond. This study addresses the issues associated with effectively leveraging infrasound for border

monitoring applications.

The three main infrasound challenges are background noise suppression, source discrimination, and propagation characterization. Noise suppression can be accomplished through either a spatial noise filter with a centralize sensor or with a field of discrete sensors spread over a given area. The infrasound frequency band of interest, generally a few tenths of a Hertz up to 20 Hz, is rich with both man-made and natural source signals. Discriminating sources of interest can be accomplished through categorization of signal properties such as center frequency, bandwidth, and duration. Once a source is identified, predicting features of the propagation drive the ability to pursue source localization and classification.

The study also presents concept of operations for an infrasound border monitoring system. One substantiation involves a rapidly deployable UGS system that uses infrasound as one piece in a multi-sensor suite. Multiple nodes would be distribution over a surveillance corridor to provide geometric look diversity. When a target of interest is identified, exfiltration of synthesize data would alert a UAV or other border asset for further investigation.

7693-44, Session 8

Nanoengineered chemical and biological sensors with unprecedented sensitivity based on SERS: opportunities and challenges

M. Moskovits, Univ. of California, Santa Barbara (United States) and API Nanotronics Corp. (United States)

No abstract available

7693-45, Session 8

Free-surface microfluidics for control of SERS hot-spot formation

C. D. Meinhart, Univ. of California, Santa Barbara (United States)

No abstract available

7693-46, Session 8

Bio-inspired networks for command and control

J. P. Hespanha, Univ. of California, Santa Barbara (United States)

No abstract available

7693-47, Session 8

Terrestrial microbial fuel cells: long-term, reliable power source for covert sensing

M. Chiu, Trophos Energy, Inc. (United States)

No abstract available

7693-48, Session 8

Cell bioprinting as a potential high-throughput method for fabricating cell-based biosensors (CBBS)

S. Moon, Brigham and Women's Hospital (United States); E.

M. Carapezza, Defense Advanced Research Projects Agency (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); C. Klapperich, Boston Univ. (United States); U. Demirci, Harvard Medical School (United States)

Cell-based biosensors (CBBs) are important tools for biosecurity applications and rapid diagnostics. Current CBBs technologies have challenges with cell immobilization and high throughput fabrication. We address these challenges by investigating the feasibility of bioprinting cell-laden hydrogels. Such a capability will allow fabrication of CBBs at high throughput. Further, the cell response was monitored by a lensless charge-coupled device (CCD) which has the potential to decrease monitoring cost and allow portability. We showed (i) a cell patterning platform, which was used to immobilize collagen droplets containing cells (i.e., primary rat smooth muscle cells) with spatial control, (ii) printed cell viability was high (> 94%) and the printed cells proliferated over five days, (iii) the cells responded to environmental stimuli (e.g. temperature change and lysis by added de-ionized water). These changes were quantified by change in morphology, i.e. decreasing cell size (~ 3000 μm2 at t = 0; ~ 600 μm2 at t = 16 hours). (iv) The developed lensless approach detected the cell morphology change under environmental stimuli. This is a first step to achieve portable CBBs. These results show that patterning cell encapsulating hydrogels could enable CBB biosensor fabrication at high throughput. Further, the lensless approaches enable monitoring limited but useful cellular responses to environmental stimuli over a wide field of view (as large as 37.25 mm × 25.70 mm).

7693-49, Session 8

BackyardNet: microbial fuel-cell powered distributed sensor network demonstration

M. Gay, Trophos Energy, Inc. (United States)

No abstract available

7693-50, Session 9

Seismic-acoustic communication for UGS

J. Cechak, Military Academy/Brno (Czech Republic)

The paper deals with Unattended Ground Sensors (UGS) and takes into consideration both present and future aspects of the practical deployment of this equipment under conditions of Electronic Warfare (EW), including the integration of UGS into a joint system using the Unmanned Aircraft System (UAS). The field-end UGS that are currently used and described in the literature usually communicate with Intelligent Gateway through two-way secure communication. If, however, a higher coverage of the area of interest is required, the number of UGS must be increased accordingly, which is associated with the risk of being detected by enemy EW-SIGINT systems because of denser RF operation. An increase in the coverage of area of interest whilst simultaneously maintaining a reasonable number of UGS installations is possible provided that the existing UGS are supplemented with a group of supporting passive sensors - nodes that communicate with UGS via signals of seismic surface waves. This principle can be applied since each UGS is, as standard, equipped with a geophone; therefore, it is also able to receive data signals from supporting nodes without problems. The main advantage of nodes conceived in this way using seismic communication is the opportunity to have them installed completely underground without the giveaway sign of a visible antenna, thus reducing the risk of their potential detection by the enemy.

The first part of the paper deals with the possibilities, characteristics and useable properties of seismic-acoustic communication in the group of nodes, supplementing the information coverage of existing UGS, including the selection of a suitable working frequency band for seismic communication.

The second part of the paper then describes an alternative method of communication between nodes and UGS using VLF radio

communication, and analyses the design and real properties of a proposed communication channel in VLF band, the design of a loop antenna and its mechanical construction. The interim conclusions of each section generalize the results of seismic-acoustic and radio VLF communications as verified in practice, and describe both the advantages and disadvantages of communication channels defined in this way.

The third part of the paper deals with the possibility of integrating the nodes-UGS to a central system consisting of a UAS device. It covers the design and an energy evaluation of a system operating on the principle of data selection from UGS. In addition, the paper includes illustrative photographs of the practical design and graphic results of real measurements.

7693-51, Session 9

Flexible gateway architecture

D. Garigen, Harris Corp. (United States)

Unmanned Ground Sensors (UGS) have seen resurgence in recent years for use in a growing number of remote surveillance applications. These sensors can provide a wide range of information to assist an analyst in recognizing the type of intrusion detected. One key challenge to these systems, due to a lack of standards and vast variety of application requirements, is disseminating this information in a manner that is useful to the user. To address this challenge, we present a flexible intelligent gateway architecture that uses distributed processing to receive, process, and redistribute this information. Dedicating a specific processor to each major function allows the users to customize their solutions to meet their needs with minimum development costs. Components like long haul communications links, external camera systems, microphones, etc. can easily be adapted. Also, the information can easily be formatted to work with the users' favorite PC application or situational awareness platform. Some examples of systems are illustrated including a sensor triggered remote surveillance system, using wireless streaming audio and video in an over-the-air network. The high level architecture of the system will be discussed, along with some existing systems that have been adapted to work with this design.

7693-52, Session 9

A software defined radio architecture for a forward deployed, universal multisensor video viewer

H. M. Sasaki, P. E. Voglewede, Harris Corp. (United States)

As more and more video-capable surveillance assets are being deployed in theater, it is apparent that the video information is not propagating to the forward forces rapidly enough to significantly increase their effectiveness. Harris has introduced a new Intelligence, Surveillance and Reconnaissance (ISR) monitoring platform in a unique Software Defined Radio (SDR) architecture which will allow the system to become a universal multi-sensor video viewer. The Universal ISR Receiver combines a field proven handheld package designed for forward deployed soldiers, an expandable SDR architecture that will grow with the future and ultimately provides actionable intelligence directly to the soldiers in the field. This universal receiver platform can be used to monitor video from UAV and UAS aerial feeds, from concealed UGS feeds like Falcon Watch and from vehicle mounted long-range surveillance systems. A single platform provides a lightweight approach for soldiers to increase their effectiveness by allowing them to increase their situational awareness by tapping into available sensor video feeds directly from their forward location.

7693-53, Session 9

Atmospheric transmission at ~1.55 μm for free-space optical communication

J. W. Zeller, T. Manzur, Naval Undersea Warfare Ctr. (United States)

Free-space optics (FSO) holds the potential for high bandwidth communication, but atmospheric conditions can significantly affect the capability of a communication system to transfer information successfully. The effects of atmosphere on FSO communication and consequent optimal wavelength range for transmission are investigated through MODTRAN-based modeling of the ~1.5-1.7 μm SWIR transmission band for multiple elevation angles in atmospheric conditions including Navy maritime, desert extinction, and various levels of rain and fog. For surface-to-surface and surface-to-air free-space optical communication networks, beam transmission was also simulated from different relevant elevations characterized by respective distances to horizon (for a horizontal path) and corresponding areas of coverage. The atmospheric, free-space, and scintillation losses are calculated for the various FSO configurations in view to determine incident beam power required for successful data transmission. These theoretical results are to be compared with experimental data from a 1 km FSO link test with a horizontal path at a height of 4 ft above the surface. Using advanced tunable laser sources to provide illumination across wavelength ranges, particularly around the eye-safe 1.55 μm wavelength, it should be possible to overcome transmission limitations associated with adverse weather and atmospheric conditions.

7693-54, Session 9

Twitter as a smart social sensor

A. Khrabrov, G. F. Stocco, G. V. Cybenko, Dartmouth College (United States)

We examine Twitter data streaming in real time and treat it as a sensor. Twitter is a social network which pioneered microblogging with the messages fitting an SMS, and a variety of clients, browsers, smart phones and PDAs are used for status updates by individuals, businesses, media outlets and even devices all over the world. Often an aggregate trend of such statuses may represent an important development in the world, which has been demonstrated with the Iran and Moldova elections and the anniversary of the Tiananmen in China.

We propose using Twitter as a sensor, tracking individuals and communities of interest, and characterizing individual roles and dynamics of their communications. We developed a nover algorithm of community identification in social networks based on direct communication, as opposed to linking. We show ways to find communities of interest and then browse their neighborhoods by either similarity or diversity of individuals and groups adjacent to the one of interest. We use frequent collocations and statistically improbable phrases to summarize the focus of the community, giving a quick overview of its main topics.

We consider different ways to seed our communities, such as by topic or geo-location. Many Twitter clients are declaring or reporting their location, which allows for geo-local trend tracking and urban sensing. We examine several ways of performing geosending and comparing it to topic search, to find interesting communities in specific locales.

Overall, our methods provide insight into the largest social sensor network in the world and constitute a platform for social sensing.

7693-59, Session 11

Enhanced technologies for unattended ground sensor systems

D. C. Hartup, L-3 Communications Nova Engineering (United States)

Progress in several technical areas is being leveraged to advantage in Unattended Ground Sensor (UGS) systems. This paper discusses advanced technologies that are appropriate for use in UGS systems. While some technologies provide evolutionary improvements, other technologies result in revolutionary performance advancements for UGS systems. Specific technologies discussed include wireless cameras and viewers, commercial PDA based system programmers and monitors, new materials and techniques for packaging improvements, low power cueing sensor radios, advanced long-haul terrestrial and SATCOM radios, networked communications, standards that permit universal interoperability and plug-and-play capability, advanced target detection algorithms, high pixel count cameras for license plate and facial recognition, small cameras that provide large stand-off distances, video transmissions of target activity instead of still images, sensor fusion algorithms, and control center hardware. The impact of each technology on the overall UGS system architecture is discussed, along with the advantages provided to UGS system users. Areas of analysis include required camera parameters as a function of stand-off distance for license plate and facial recognition applications, power consumption for wireless cameras and viewers, sensor fusion communication requirements, and requirements to practically implement video transmission through UGS systems. Examples of devices that have already been fielded using technology from several of these areas are given.

7693-60, Session 11

UGS technology driven application expansion

J. H. McQuiddy, McQ, Inc. (United States)

UGS usage has transitioned from military applications in Vietnam under the Igloo White Program directed at detecting enemy movements to much more sophisticated applications for classifying activity, tracking targets, identifying targets, and providing real time target response. The era of individual sensors has now moved into an era of collaborative sensors. The technologies behind this increased collaborative capability include networking many sensors together, performing complex processing of target features, integrating multiple sensing phenomenologies, fusing information from many sources, and presenting the user with advanced information visualization for events of interests. Behind the technology enhancements is a steady parade of advances in signal processing electronics, sensors, communications, network connectivity, day and night imagers, image processing, GPS positioning and timing, and importantly in open standards for storing and disseminating information as opposed to transmitting data. The continual influx of more advanced electronics information processing, networking, sensor technology, and graphical user interfaces will push UGS into far more widespread applications because the size and cost will dramatically decrease while the performance significantly increases. This process, already in place, will lead to a new era of ubiquitous UGS applications for military, law enforcement, transportation, public activity management, industrial security, and personnel security. Small, low power consumption, network protocol based, low cost sensors will feed databases that are accessed by users via networks for information processing and user display of critical items of interest. The broader ubiquitous applications mean sensors will increase in importance and the UGS moniker may no longer be appropriate.

7693-61, Session 11

Smart sensor end-to-end architecture considerations

E. Chaum, Naval Undersea Warfare Ctr. (United States)

Smart sensors are critical components in distributed, integrated sensor systems and architectures. With the emphasis on "smart," sensor-side processing is essential in unattended and high-performance applications and architectures. Sensor-embedded intelligent processing technologies create opportunities to efficiently process, communicate, and dynamically adapt to changing requirements. Distributing and managing the

computational processing, end-to-end, in an implementation architecture poses new design, standardization, and interoperability challenges.

This paper examines requirements drivers for smart sensor designs and explores implications for end-to-end open architecture and sensor management. Additionally, it considers the need for standardization as an important enabler of networked capability, information assurance, and acquisition affordability.

7693-62, Session 11

Affordable next-generation UGS development and testing

M. A. Winston, B. M. Jones, McQ, Inc. (United States)

Unattended Ground Sensors (UGS) are valuable tools for the U.S. military and border patrol, however, their utility is often limited due to their cost, size, and weight. Recently specific advances in micro power electronics, transducers, packaging, and signal processing techniques have enabled the development of a small, lightweight, and affordable UGS. This sensor was originally intended for small unit clearing/monitoring operations and has since evolved to achieve detection performance comparable to state-of-the-art UGS. To meet a broader mission capability, battery life and detection capabilities have been extended and affordable networked cameras and repeaters have been developed. This paper will provide an overview of the key enabling technologies for affordable UGS, provide an overview and enhancements of this affordable UGS system, and review results of system testing.

7693-63, Session 11

Compact, low-cost sensor for situational awareness

D. S. Franco, T. D. Reeves, Solid State Scientific Corp. (United States)

Situational awareness (SA) cameras often are adjunct sensors to pre-existing intelligence, surveillance and reconnaissance (ISR) systems. Consequently, the SA cameras must accommodate the form, fit and function requirements of the ISR system. Solid State Scientific Corporation has developed a short-wave infrared camera that operates with a very wide field of view lens at high frame rates with no adjustable parameters that was designed to fit around an ISR system. The presentation will provide a description of this compact, low-cost camera along with camera performance results.

7693-64, Session 11

SCORPION II persistent surveillance system update

M. A. Coster, Northrop Grumman-Xetron (United States)

This paper updates the improvements and benefits demonstrated in the next generation Northrop Grumman SCORPION II family of persistent surveillance and target recognition systems produced by the Xetron campus in Cincinnati, Ohio. SCORPION II reduces the size, weight, and cost of all SCORPION components in a flexible, field programmable system that is easier to conceal, backward compatible, and enables integration of over fifty different Unattended Ground Sensor (UGS) and camera types from a variety of manufacturers, with a modular approach to supporting multiple Line of Sight (LOS) and Beyond Line of Sight (BLOS) communications interfaces. Since 1998 Northrop Grumman has been integrating best in class sensors with its proven universal modular Gateway to provide encrypted data exfiltration to Common Operational Picture (COP) systems and remote sensor command and control. In addition to feeding COP systems, SCORPION and SCORPION II data can be directly processed using a common sensor status graphical user

interface (GUI) that allows for viewing and analysis of images and sensor data from up to seven hundred SCORPION system Gateways on single or multiple displays. This GUI enables a large amount of sensor data and imagery to be used for actionable intelligence as well as remote sensor command and control by a minimum number of analysts.

7693-65, Session 11

A roadmap to truly disposable unattended ground sensor systems (UGS)

B. M. Jones, McQ, Inc. (United States)

In the last two decades, research by McQ Inc. and others has led to substantial advances in the performance of unattended ground sensor (UGS) systems. These advancements include: extremely long battery life; small, robust packaging; high performance detection and classification algorithms; multimodal, multispectral sensors; long range communications; air droppable delivery; fully integrated sensor management; multi-sensor situational awareness and data fusion; advanced video detection and optical sensor development; and others. What this research has shown is that there is a great deal that existing technology can do to solve users' intelligence, surveillance, and reconnaissance (ISR) requirements using UGS sensors. However, in spite of these advances, UGS systems have not enjoyed widespread use in either DoD, DHS or with law enforcement agencies (LEA). Although requirements differ from agency to agency and application to application, the primary factor that limits more widespread use of UGS systems is cost. Cost determines how many sensors an agency can buy and how they are used operationally. Only when sensors cost $100 or less will they be considered truly disposable. The focus of this paper is to present the technical considerations and a roadmap for producing truly low cost UGS sensors. Achieving this goal will then create within the DoD, DHS, LEA and other communities' requirements for UGS systems for a wide variety of uses that were never seriously considered previously because of cost. The implications are significant and will lead to an explosion in the number of UGS systems made and used on an annual basis.

Conference 7694: Ground/Air Multi-Sensor Interoperability, Integration, and Networking for Persistent ISR

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Ground/Air Multi-Sensor Interoperability, Integration, and Networking for Persistent ISR

7694-01, Session 1

Ground/air multisensor interoperability, integration, and networking for persistent ISR: what, why, who

M. A. Kolodny, U.S. Army Research Lab. (United States)

Description of pupose, focus and agenda of this new SPIR DSS Conference

7694-02, Session 1

Planning for coalition materiel interoperability

R. F. Young, U.S. Army Research Office (United States)

Coalition partners experience a number of technological challenges both in peacetime training exercises and operations while deployed. These run the gamut from the simple such as engine fuel compatibility, to the complex and sensitive like communication protocols. The American, British, Canadian, Australian, and New Zealand Armies' (ABCA) program has established the Science and Technology Support Group to vet materiel interoperability challenges and facilitate solutions in the national and coalition-partnership fora. This presentation will address policies and procedures established by ABCA as well as some of the extraordinary challenges facing the US Army acquisition infrastructure in execution.

7694-03, Session 1

Optimising the deployment of airborne heterogeneous sensors for persistent ISR missions

A. J. Barnett, G. Pearson, R. I. Young, Defence Science and Technology Lab. (United Kingdom)

Ultimately, the success of any persistent ISR system will be judged by the quality (timeliness, value) of the intelligence products that it delivers. In deploying multiple sensors to gather intelligence there is frequently a tripartite trade off to be made between the physical constraints imposed by the sensor and platform performance both against the requirements of that mission and against the information needs of other users. Thus there is a need when working with constrained resources to optimise deployment through intelligent tasking to maximise the information quality without contradictory or over-constraining requirements and whilst maintaining mission efficiency.

This paper considers recent advancements in defining mission specifications to better facilitate the optimum deployment of sensors against competing requirements and the needs of different missions.

Considerations will be based against a scenario of a number of airborne vehicles carrying heterogeneous imaging sensors tasked for mine detection missions

7694-04, Session 1

Aspects of sensor data fusion in interoperable ISR systems of systems for wide-area ground surveillance

W. Koch, M. Ulmke, Fraunhofer FKIE (Germany)

A basic component of C4ISTAR information systems, modular and flexibly designed as "systems of systems", is the combination of sensor systems and data bases with appropriate sensor data and information fusion sub-systems. The objective at this level is the production of timely, consistent and, above all, sufficiently complete and detailed "situation pictures", which electronically represent a complex and dynamically evolving overall scenario in the air, on the ground, at sea, or in an urban environment. The concrete operational requirements and restrictions in a given application define the particular information sources to be considered and data fusion techniques to be used.

Rather mature examples of information systems, where advanced sensor data fusion technology is among its central pillars, is given by distributed, coalition-wide C4ISTAR systems of systems for wide-area ground sur-veillance. They mirror many of the aspects previously addressed. By collaboratively using interoperable sensor and data exploitation systems in coalition operations, these systems have been designed to improve situational awareness of military commanders over the various levels of the decision making hierarchy. Based on appropri-ate concepts of employment and the corresponding tactical procedures, technological tools for Collection, Coor-dination and Intelligence Requirements Management (CCIRM) are initiated by individual sensor service requests of deployed action forces. The CCIRM tools produce mission plans according to superordinate priorities, task sensor systems with appropriate data acquisition missions, initiate data exploitation and fusion of the produced sensor data streams in order to obtain high-quality reconnaissance information, and, last but not least, guarantee the feedback of the right information to the requesting forces at the right instant of time.

Within this context, we discuss sensor data fusion aspects that are aiming at the generation of higher-level in-formation according to the JDL model of data fusion. In particular, two issues are addressed:

1. Tracking-derived Situation Elements. The primary objective of multiple sensor target tracking is to explore the underlying target kinematics such as position, velocity, or acceleration. In other words, standard target track-ing applications gain information related to 'Level 1 Fusion' according to the well-established terminology of the JDL model. Kinematic data of this type, however, are by no means the only information to be derived from tar-get tracks. In many cases, reliable and quantitative higher level information according to the JDL terminology can be obtained. To be more concrete, wide-area ground surveillance is considered here as an important real-world example serving as a paradigm for other challenging tracking and fusion applications.

2. Anomaly Detection in Tracking Data Bases. Anomaly detection can be regarded as a process of information fusion that combines incomplete and imperfect pieces of mutually complementary sensor data and context in-formation in such a way that the attention of human decision makers or decision making systems is focused on particular events that are "irregular" or may cause harm and thus require special actions, such as exploiting more specialized sensors or initiating appropriate activities by operators. Fusion-based anomaly detection thus im-proves situational awareness. What is actually meant by "regular" or "irregular" events is higher-level informa-tion itself that depends on the context of the underlying application. Here, it is either assumed to be a priori known or to be learned from statistical long-time analysis of typical situations.

7694-05, Session 1

Distributed policy based access to networked heterogeneous ISR data sources

G. A. Bent, D. R. Vyvyan, IBM United Kingdom Ltd. (United Kingdom)

Within a coalition environment, ad hoc Communities of Interest (CoI's) come together, perhaps for only a short time, with different sensors, sensor platforms, data fusion elements, and networks to conduct a task (or set of tasks) with different coalition members taking different roles. In such a coalition, each organization will have its own inherent restrictions on how it will interact with the others. These are usually stated as a set of policies, including security and privacy policies. The capability that we want to enable for a coalition operation is to provide access to information from any coalition partner in conformance with the policies of all. The challenge in supporting such ad-hoc networked operations is that of providing efficient access to distributed sources of data, where the applications requiring the data do not have knowledge of the location of the data within the network. To address this challenge the International Technology Alliance (ITA) program has been developing the concept of a Dynamic Distributed Federated Database (DDFD), also know as a Gaian Database. This type of database provides a means for accessing data across a network of distributed heterogeneous data sources where access to the information is controlled by a mixture of local and global policies. The paper will describe how a network of disparate ISR elements can be expressed as a DDFD and how this approach enables sensor and information sources to be combined, fused and/or discovered autonomously or semi-autonomously using formally defined local and global policies.

7694-06, Session 2

International Armaments Cooperation

K. M. Hithe, U. S. Air Force (United States)

No abstract available

7694-08, Session 2

Management of coalition sensor networks

D. C. Verma, IBM Thomas J. Watson Research Ctr. (United States); T. Brown, The Graduate Ctr. (United States)

Wireless sensor networks are used in a variety of ISR applications, and play an important role in the effectiveness of tactical operations. As the number and variety of sensor types, their information elements and fusion capability increase, the sensor networks grow more complex and explicit attention needs to be given to the management and control of these type networks. In the context of coalition operations, additional complications arise because of the difference in policies and procedures regarding collection and handling of sensor equipment among different members of the coalition.

Current work in wireless sensor management has tended to focus on algorithms to monitor and identify the topology of wireless sensor networks. While an important aspect of sensor network management, monitoring and discovery alone are just a small fraction of the issues that need to be deal within the management of sensor networks. Another significant limitation of the current academic work in wireless sensor management is that it has tried to extend the model of traditional network management to sensors. However, many of the conditions that are implicit in traditional networks, e.g. a continuous access to the monitored device, or little cost in retrieving information from a sensor, are not applicable in the context of military sensor networks. Furthermore, the life-cycle of a wireless sensor network tends to be quite different than a traditional router or server in a wired network. A more comprehensive management framework to deal with sensor networks is needed that expands beyond the current state of the art.

Tactical operations are characterized by a large number of operations, each of which involves a small finite set of sensors that are commissioned and then decommissioned or redeployed for another mission. A sensor asset may need to be moved across different missions, with a potential change in its properties, such as location or configuration. A significant complexity in wireless sensor network may thus deal with the complexities of managing and maintaining an inventory of the sensors that may be available during operations. Even when deployed in the operation of the network, the management functions that need to be performed for sensor networks will be very different than the ones in traditional networks.

In this paper, we begin by formulating a life-cycle through which sensor assets need to traverse as they are used in a mission. The life-cycle contains the procurement of a sensor for an operation, validating its applicability in a specific mission, being used in the mission operation, and then being retasked or returned to the inventory of available assets. For each stage of the life-cycle, as well as the transitions that are made among the life-cycle stages, we then formulate the typical management operations that will need to be performed. These management operations would include the traditional management functions of fault, configuration, accounting, performance and security, but the meaning and magnitude of each of these functions will be quite different in each of the life-cycle stages. We describe the appropriate modification of the FCAPS paradigm in each of the stages of sensor life-cycle.

Having identified the management paradigm in each of the stages of the life-cycle, we then discuss the architecture of management at each of the life-cycle stages that will result in a comprehensive framework for sensor network management. During some of the lifecycle stages, the sensors are turned off or physically removed from other sensors in the networks natural course of operation, and thus the management paradigm in those life-cycle stages has to deal with this unique aspect. The implication to the coalition operations are also dramatically different in each of the life-cycle stages.

Taken together, this paper will present a comprehensive life-cycle based architecture for sensor network management in the context of coalition operations.

7694-09, Session 2

PWAS S2O: The UK's airborne multisensor demonstrator program for persistent wide-area surveillance

S. Rouse, B. McGrath, R. I. Young, Defence Science and Technology Lab. (United Kingdom)

Improved persistent surveillance capability is a high priority for UK armed forces. Experience in current operations has demonstrated that wide area surveillance and sensing would be a vital component in the fight against the insurgent threat; for tracking patterns and behaviours of opponents and their networks; and for overall support to our situational understanding and dominance of the ground in urban and/or asymmetric warfare. Emerging technologies, an open architecture and a new approach to acquisition will enable the UK to acquire this critical capability in a timely manner.

The UK MoD is currently engaged in a rapid demonstration of this class of capability. Its Persistent Wide Area Surveillance (PWAS) integrated multiple sensor demonstrator is a multiple-strand program to rapidly integrate mature equipment into service, whilst in parallel evolving technology updates based on advances in platform, payload, and processing development. The principal demonstrator strands are: airborne platform, sensor package, processing element, communications and open architecture.

This paper discusses the outcomes of efforts in these strands so far and describes the future plan. Analysis of the military requirement has led to options for the air platform; a robust methodology has been employed to determine the make-up of the sensor package. The complementary and synergistic relationship between sensor types leads to opportunities for automatic algorithms to self-cue the sensors and to fuse their information. Finally, an important part of the program is the development

of an open, scalable architecture for the payload, to facilitate evolution of capability and wide exploitation.

7694-10, Session 3

Generic services architecture for the integration and sharing of

vehicular and extra-vehicular sensors

F. A. Bergamaschi, N. Peach, D. Conway-Jones, IBM United Kingdom Ltd. (United Kingdom)

In this paper we present a Generic Services Architecture (GSA) for the integration and sharing of in-vehicle and extra-vehicle sensors. The proposed architecture addresses the need for: a) easy integration with legacy and future systems, and architectures; b) scales from individual sensors, individual human users, vehicles and patrols to battle groups and brigades; c) allow rapid introduction of new capabilities in response to a changing operational scenario; d) be agnostic of communications systems, devices, operating systems and computer platforms.

The GSA leverages and extend the use of research output and tools developed by the International technology Alliance (ITA) programme (e.g., ITA Sensor Fabric and the Policy Libraries) and promotes the use of off-the-shelf hardware, and software which is advantageous from the aspect of easy of upgrading, lower cost of support and replacement, and speed of re-deploying platforms through a "fitted for but not with" approach.

The GSA exploits the services orientated architectural environment provided by the ITA Sensor Fabric to enhance the capability of legacy solutions and applications by enabling information exchange between them, by for example providing direct near real-time communication between legacy systems. The SOA approach: a) reduces the requirement for form completion by front line troops; b) improves reliability as a result of reliability growth and pre-emptive action due to more accurate reporting; c) reduces stock holding requirements due to more accurate specification of need; d) reduces procurement expenditure due to more accurate specification of need.

A prototype implementation demonstrator of this architecture has demonstrated its utility to fusing, exploiting and sharing situational awareness information for force protection, and platform and device health and usage information for logistics and deployment management. The prototype demonstrated the ability to fuse, store, analyse and retrieve information during a mission as well as for post-mission analysis and mission rehearsal, and the ability to accommodate rapid changes in sensor and communications availability typical of a combat scenario.

A generic mobile platform (Off-Road Vehicle) was fitted with the prototype demonstrator infrastructure including a mesh communications network, embedded architectural services processor, tablet user displays, visual sensors and processors, and a Situational Awareness application. The ability to exchange information with other platforms was achieved through communications links with other platforms, unattended ground sensors, a mobile user with a Personal Digital Assistant (PDA), and a simulation environment (used to simulate large platforms and a small Headquarters (HQ)).

7694-11, Session 3

Persistent surveillance using mutually visible robotic formations

E. Stump, Univ. of Pennsylvania (United States); B. M. Sadler, U.S. Army Research Lab. (United States)

We consider the problem of deploying mobile robots to create a mutually-visible formation between stationary and mobile targets in a known environment. A mutually-visible formation is a placement where each agent or target is connected to all others through a sequence of visibility pairings. We discretize the environment in a manner conducive to visibility calculations, and, as targets shift, we use dynamic

programming to find formations that preserve the visibility topology and minimize movement. The approach can be generalized out-of-plane with a suitable decomposition and discretized visibility computation, allowing for both air and ground robots to cooperatively deploy to maintain visibility in spatial environments.

7694-12, Session 3

An automatic UAV search, routing, and sensor tasking algorithm for persistent surveillance

G. E. Collins, Toyon Research Corp. (United States)

Substantial scientific research has addressed the problems of automatic search, routing, and/or sensor tasking for UAVs, producing many good algorithms for each task. But UAV surveillance missions typically include combinations of these tasks, so an algorithm that can manage and control UAVs through multiple tasks will help further automate the UAV control process and ease UAV operator management duties. The algorithm in this paper maintains automatic control of UAV search, routing, tracking, and sensor tasking. In particular, the algorithm employs a cooperative graph-based search when target states are unknown or have very large position covariance. If target states become more localized, the algorithm switches to route UAV(s) for target intercept. If a UAV is in close proximity to a target, waypoints and sensor commands are optimized over shorter future horizons, with the objective of maintaining the best sensor-to-target viewing geometry.

7694-13, Session 3

User evaluation of a GUI for controlling an autonomous persistent surveillance team

P. Scerri, K. Sycara, S. Owens, Carnegie Mellon Univ. (United States); M. Lewis, Univ. of Pittsburgh (United States)

This paper presents results of an evaluation by 16 Army Lieutenants of a graphical user interface, built on top of FalconView, for controlling up to 50 manned and unmanned assets performing a search and destroy mission. Assets simulated included armed and unarmed UAVs, UGV, intelligent minefields and manned Humvees. The simulated FCS assets autonomously executed team-oriented plans, specifying joint mission objectives but not execution details, requested by the operator. The simulation captured many salient details of a realistic future FCS scenario, including limited communications, imperfect automatic target recognition and the presence of civilians.

The subjects were very successful at mission completion, losing Surprisingly they requested even more autonomy, in particular for auxiliary tasks such as getting permission to use air space. However, they wanted much more information fed back from the autonomous vehicles. Clearly more information should have been fed back to the operators, but serious issues of screen clutter and information overload will need to be dealt with as the system becomes capable of feeding this information back.

7694-14, Session 3

Environmental awareness for sensor and emitter employment (EASEE)

K. K. Yamamoto, D. K. Wilson, R. Bates, U.S. Army Cold Regions Research and Engineering Lab. (United States)

Environmental Awareness for Sensor and Emitter Employment (EASEE) is a flexible, object-oriented software design for predicting environmental effects on the performance of battlefield sensors and detectability of signal emitters. Its decision-support framework facilitates many sensor and emitter modalities and can be incorporated into battlespace command and control (C2) systems. Other potential applications include

immersive simulation, force-on-force simulation, and virtual prototyping of sensor systems and signal processing algorithms.

By identifying and encoding common characteristics of Army problems involving multimodal signal transmission and sensing into a flexible software architecture in the Java programming language, EASEE seeks to provide an application interface enabling rapid integration of diverse signal generation, propagation, and sensor models that can be implemented in many client-server environments. Its explicit probabilistic modeling of signals, systematic consideration of many complex environmental and mission-related factors affecting signal generation and propagation, and computation of statistical metrics characterizing sensor performance facilitate a highly flexible approach to sensor modeling and simulation. EASEE aims to integrate many disparate statistical formulations for modeling and processing many types of signals, including infrared, acoustic, seismic, radio frequency, and chemical/biological.

EASEE includes objects for representing sensor data, inferences for target detection and/or direction, signal transmission and processing, and state information (such as time and place). Various transmission and processing objects are further grouped into platform objects, which fuse data to make various probabilistic predictions of interest. Objects representing atmospheric and terrain environments with varying degrees of fidelity enable modeling of signal generation and propagation in diverse and complex environments.

7694-53, Poster Session

An operationally focused routing strategy for military networks

C. Cross, U.S. Air Force (United States)

Military operations require that the availability and timeliness of information be tailored to the needs of both the source and the user. The quality of service and bandwidth provided by networks must take into consideration real time operations with low latency tolerance while also providing service for information of a more administrative nature that can withstand latencies ranging from hours to days. Both the sender and the user of this information operate within the military command structure whereby the importance of the information and its associated actionable value is tied to the chain of command. The type and size of information ranges from streaming video to routine text and chat, each having its own priority need and data latency requirement. Lastly, the geographic span of military operations ranges from globally to locally and the physical constraints of passing this information also have an impact on routing of the data and its latency.

Commercial technologies offer the benefit of having a large customer base and associated research and development effort which has the potential to provide high quality of service at lower cost for military applications. While the hardware, and to a large degree the software can be directly ported to military applications, the routing strategies may not fully meet the needs associated with that mentioned in the previous paragraph. These routing strategies need to consider the unique needs of military operations, and can benefit from some prioritization based on the structure of the military operating environment. Bandwidth has historically and will continue to be an issue due to the fact that as infrastructure grows to support capability, the desire to have more real-time information also grows. The intent of this research is to investigate if a routing strategy based on the unique requirements of military operations can provide enhanced quality of service. This strategy considers three variables in the allocation of information; Mission, Chain of Command, and Location.

I expect that the analysis will demonstrate that the prioritized routing strategy is more effective at delivering critical information to users as available bandwidth decreases. The results of this research and analysis will be provided in the conference paper and will help to establish the requirements for further development and implementation of routing strategies for military networks.

7694-54, Poster Session

Robust extended target detection using nonlinear morphological operations

H. Chen, C. Volpe, A. Menozzi, T. Sherrill, S. R. Snarski, M. Wille, Applied Research Associates, Inc. (United States)

The current bottleneck in wide area persistent surveillance missions is slow exploitation and analysis (real-time and forensic) by human analysts. We are currently developing an automated data exploitation system that can detect, track, and recognize target and threats at risk using computer vision. Automated target tracking and recognition (super-resolution) results were presented at SPIE-DSS 2009. Here we present results from a newly developed target detection process.

Depending on target size, target detection can be divided into three detection classes: unresolved targets; small extended targets; and large extended targets. The Matched Filter (MF) method is currently a popular approach for unresolved target detection using IR focal plane arrays and EO (CCD) cameras as sensor detectors. The MF method is much more difficult to apply to the extended target classes, since many different matched filters are needed to match the different target shapes and intensity profiles that can exist. The MF method does not adequately address non-fixed target shapes (e.g., walking or running).

Here we present an approach for robust target detection that can detect targets of different sizes and shapes (fixed/non-fixed) using basic non-linear morphological operations: dilation, erosion, opening, closing, different connectivity, etc. Furthermore, instead of using the traditional top-down Constant-False-Alarm-Rate thresholding approach as used in the MF method, an adaptive bottom-up deep thresholding approach has been developed. Combined with a target size/shape analysis, this approach can considerably reduce false detection rate. Applications for bullet detection as well as ground vehicle and human detection under heavy background clutter will be presented.

7694-55, Poster Session

Low-resolution vehicle tracking using dense and reduced local gradient features maps

M. Dessauer, S. Dua, Louisiana Tech Univ. (United States)

We present a novel method to quickly detect and track objects of low resolution within an image frame by comparing dense, localized oriented gradient features at multiple scales with a object chip. The proposed method uses vector correlation between sets of oriented Haar filter responses from within a local window and a object library to create similarity maps, where peaks indicate high object probability. Interest points are chosen based on object shape and size so that each point represents both a distinct spatial location and shape segment of the object. Each interest point is then independently searched in subsequent frames, where multiple similarity maps are fused to create a single object probability map. This method executes in real time by reducing feature calculations through Harris-point thresholding and approximating using box filters and integral images. The calculated features are both rotational and illumination invariant by calculating interest point orientations and normalizing feature vector scale. The method creates a feature set from a small localized area, allowing for accurate detections of low pixel on object scenarios. This approach can also be extended to include detection of partially occluded objects through calculating individual interest point feature vector correlations and clustering points together. We have tested the method on a subset of the Columbus Large Image Format (CLIF) 2007 Dataset, which provides various low-pixel-on-object moving and stationary vehicles with varying operating conditions. This method provides accurate results with minimal parameter tuning for robust implementation on aerial, low pixel-on-object data sets for automated classification applications.

7694-56, Poster Session

Wavelet-based optical flow object detection, motion estimation, and tracking on moving vehicles

M. Dessauer, S. Dua, Louisiana Tech Univ. (United States)

We have studied the performance of phase-based optical flow using multi-scale wavelet approximations for object detection and motion estimation. Optical flow based tracking methods offer the promise of precise, accurate and reliable analysis of motion, but they suffer from several challenges such as elimination of background movement, estimation of flow velocity and optimal feature selection. Wavelet approximations can offer similar benefits and retain spatial information at coarser scales, while optical flow estimation increases with the reduction of finer details of moving objects. Optical flow methods often suffer from significant computational overload. In this study, we have identified necessary processing steps to increase detection and estimation accuracy, while effectively reducing computation time through the reduction of the image frame size. We implement an object tracking algorithm using the optical flow calculated from a phase change between representative coarse wavelet coefficients in subsequent image frames. The optical flow algorithm calculates object speed and direction by measuring the rate of change of similar areas within the object. We also compare phase-based optical flow with intensity and energy-based optical flow to study which method produces superior results during specific operational conditions. The investigation demonstrates the feasibility of using phase-based optical flow using wavelet approximations for object detection, motion estimation and tracking under certain conditions that create reproducible object representation of objects in the wavelet domain. We also show that this method can work in tandem with feature based tracking methods to increase detection accuracy and provide improved motion estimation.

7694-57, Poster Session

Range and velocity independent classification of humans and animals based on object silhouettes

S. K. Chari, F. A. Smith, J. Brooks, The Univ. of Memphis (United States); R. B. Sartain, U.S. Army Research Lab. (United States); C. E. Halford, The Univ. of Memphis (United States)

This paper presents classification of humans and animals using velocity and range independent features. Video sequences of humans, animals and animals lead by humans are captured using a LWIR camera. The data is collected in urban (college campus) and rural (farms in Tennessee and US-Mexico border area in Arizona) environments. Binary profiles of the objects are then generated from the video sequences. Range independent features based on height and width are extracted and then normalized by the estimated velocity of the moving object. Classification algorithms such as Naive Bayesian, Linear Discriminant Analysis with Mahalanobis distance, K-Nearest Neighbor and Support Vector Machines are compared based on their ability to classifiy objects into humans and animals using the given features. The process is further extended to identify video sequences containing animals being lead by humans since they are of specific interest in several surveillance applications.

7694-16, Session 4

Empire Challenge: making ISR battle ready

C. Jackson, U.S. Joint Forces Command (United States)

Mr. jackson will discuss the USD(I) sponsored Empire Challenege program

7694-17, Session 4

ARL Empire Challenge 2010 initiative

M. A. Kolodny, U.S. Army Research Lab. (United States)

Provides technology initiaves beoig implemented in EC10

7694-18, Session 4

Terra Harvest Program

C. Cross, U.S. Air Force (United States)

Unattended ground sensors (UGS) have historically been designed for mission specific applications and are expensive, have limited upgrade potential, are proprietary, and lack interoperability. Current UGS cannot be rapidly reconfigured or combined for collection against varied targets as mission requirements change. The Defense Intelligence Agency initiated the Terra Harvest effort in 2009 to develop an open architecture for UGS based on new and documented commercial and DoD standards. Advances in technology and the ever changing nature of intelligence targets lends itself to an overarching software and hardware architecture with government and industry approved standards that will allow UGS users to configure system components in a plug-and-play manner from the best qualified vendors to meet emergent mission needs. The Terra Harvest program will allow this high level of flexibility and interoperability and provide increased capability to unattended sensing.

7694-19, Session 4

City Beat @ Tec^Edge

J. Graley, L. Quinn, Air Force Research Lab. (United States); A. P. Palomino, General Dynamics Advanced Information Systems (United States)

The purpose of the City Beat @ Tec^Edge program is to improve urban situation awareness through the integration, visualization and exploitation of geospatial imagery and products with sociocultural information in a layered sensing architecture. City Beat applies persistent surveillance from multiple sensors to include wide area airborne and ground level cameras to learn normal behavior patterns based on object motion. Publicly available Geographic Information Systems (GIS) and geocoded sociocultural layers such as high resolution reference imagery and terrain models, transportation networks and routes, building/area outlines (e.g., schools, parks, places of worship), census demographics, event schedules and communications (e.g., Twitter) are integrated to provide context for the direct sensor measurements. Anomaly detection algorithms incorporating normalcy models with observed behavior are being developed to automatically alert an analyst of unusual behavior for objects of interest. An interactive environment enables the analyst dynamic visualization of information layers as well as access to integrated open source analysis tools. This paper will give an overview of the City Beat program and plans, describe the system architecture and review a conceptual demonstration combining prerecorded wide area persistent surveillance imagery with an active scenario using building mounted and ground level cameras conducted in the summer of 2009 at the Ohio State University campus in Columbus, Ohio.

7694-20, Session 4

Unattended ground sensors standards working group

R. Heathcock, U.S. Dept. of Defense (United States)

The Department of Defense has established an unattended ground sensor standards working group to address the interoperability of UGS, promote competition and provide enhanced capabilities to support UGS

missions.

7694-21, Session 4

Standards and protocols for interoperation of unattended ground sensors

G. H. Stolovy, U.S. Army Research Lab. (United States)

Unattended Ground Sensor (UGS) systems have special requirements for long-duration, low-power operation, exfiltration of sensor reports and imagery over intermittent terrestrial or satellite communications channels, sensor description, management, discovery, configuration and command-and-control. This paper surveys a number existing and proposed software architectures for networked sensors, to include publish/subscribe brokered frameworks, with respect to the specific features needed for standard and protocols for UGS interoperability.

7694-22, Session 4

A roadmap for future UGS

J. H. McQuiddy, McQ, Inc. (United States)

The combination of changing technology in the marketplace and new requirements for UGS will provide a continuing force for improving the performance of UGS systems in the future. The characterization of UGS as a System has already transformed UGS from an individual sensor reporting a target detection to a user in proximity to the sensor into the current paradigm of many UGS units interacting over a network to provide much more target information. As the technology continues to move forward, the amount of target information and the precision of the information is going to advance. The requirements already are formulating for UGS Systems to go beyond classifying the target to identifying the target, providing not only the past target movement information but also projections of where the target is going, determining the difference between hostile and non hostile targets, rejecting non targets such as some categories of animals while accepting others such as pack animals, providing intuitive operations with little training needed to deploy systems, using non personnel deployment by unmanned ground and air vehicles, providing an interchangeable and interoperable architecture for sharing information across users, and developing very small and low cost UGS units, as examples of future UGS enhancements. This paper will provide examples of research underway to meet these future UGS needs and estimates of when these advances will become deployable systems.

7694-23, Session 4

Interoperability of unattended ground sensors with an open architecture controller using SensorML

J. L. Chambers, Northrop Grumman-Xetron (United States); S. Fairgrieve, Northrop Grumman Information Technology-TASC (United States); A. J. Brunck, Northrop Grumman-Xetron (United States)

Unattended Ground Sensors (UGS) from a wide range of manufacturers have difficulty interoperating with each other and common control and dissemination points. Typically, UGS data is transmitted via radio frequency (RF) or wired connections to a central location where the data can be fused together and transmitted further via satellite to a Processing, Exploitation and Dissemination (PED) system. These PED systems are charged with analyzing the data to create real-time, actionable intelligence for the war fighter. However, when several disparate sensors from different manufacturers are used, interoperability problems arise. Therefore, an UGS controller that accepts data from a wide range of sensors and helps them interoperate is essential. This paper addresses benefits derived from using Open Geospatial

Consortium (OGC) Sensor Model Language (SensorML) sensor descriptions for an UGS controller. SensorML 1.0 is an approved OGC standard and is one of the major components within the OGC Sensor Web Enablement (SWE) suite of standards. SensorML provides standard models and a XML encoding for describing any process, including the process of measurement by sensors. By incorporating SensorML, an UGS controller can accept data from various sensors from different manufacturers and interpret that data using the SensorML descriptions to allow the controller to take programmed actions and interoperate between sensors. Furthermore, SensorML can be used to translate native sensor formats once the original data has been transmitted. This makes a SensorML enabled UGS controller a powerful tool that provides situational awareness by combining multiple sensors to form a single common operational picture (COP).

7694-24, Session 5

Open architecture design of a sensor-cued video system

R. A. Johnson, P. E. Voglewede, Harris Corp. (United States)

Harris' experience with a variety of unattended ground sensor programs and customers led us to the conclusion that one size indeed does not fit all and proprietary interfaces limit a developer's and a user's ability to adapt a system to particular missions and threats. This knowledge was applied to the development of a flexible persistent unattended video surveillance capability that provides sensor cued and 'on-demand' video at line of sight ranges of 7 miles. The paper will discuss the architecture design features that allow it to be cued from a variety of UGS, use a variety of video sources and a variety of transport mechanisms.

7694-25, Session 5

Integration and interoperability of multisensor shipboard/airborne systems in a networked environment

J. Carpenter, Naval Air Warfare Ctr. Aircraft Div. (United States)

Manned and unmanned airborne systems are being developed and deployed with an increasing amount and variety of sensor platforms. Traditionally, airborne sensor systems have been operated by one or more aircrew onboard that particular platform, with little or no direct off-board command and control. However, US Navy H-60 sensor systems have long been utilized as an extension of the surface ship sensors beyond line of sight, using a point-to-point data link for sensor and tactical data exchange. This paper will present some of the considerations and challenges of modern manned and unmanned sensor integration in a networked environment.

7694-26, Session 5

Open source software-based architecture for layered sensing applications

K. L. Priddy, D. A. Uppenkamp, T. V. Rovito, B. McDonie, Air Force Research Lab. (United States)

We present an architecture for layered sensing which is constructed on open source and government off the shelf software. This architecture shows how leveraging existing open source software allows for practical graphical user interfaces along with the underlying database and messaging architecture to be rapidly assimilated and utilized in real-world applications. As an example of how this works, we present a system composed of a database and a graphical user interface which can display wide area motion imagery, ground-based sensor data and overlays from narrow field of view sensors in one composite image composed of sensor data and other metadata in separate layers on the

display. The paper describes the architecture, the pros and cons of the open source approach with results for a layered sensing application with data from multiple disparate sensors.

7694-27, Session 5

Execution-time collaborative air/ground command and control for unmanned systems

R. Ordower, SAIC (United States)

Unmanned Systems are rapidly increasing in numbers and capabilities. From 2002 to 2008 the number of robots in the Pentagon arsenal has grown from 200 to 6,000. The vast majority of these assets are Small and Tactical level assets supporting the soldier in the close battle. This creates a paradox whereby greater unmanned assets numbers requires a redirect of soldiers' roles/workload from infantry to robotics operators. Ironically, soldiers controlling the asset are "not in the fight". The resultant goal is to allow for the greater situational awareness made possible by unmanned observers without removing the boots on the ground closest to the battle.

A derived requirement is to increase autonomy of the individual asset, lessening operator involvement. However, from the brigade perspective, commander workload is stressed as well. Whole new concepts and tools for dynamic replanning and plan synchronization must be developed to integrate the multitude of additional assets. Workload reduction and efficiency in operations can be accomplished through decision aids for mission and asset management. Mission Management software sequences, allocates and routes for all tasks. Asset management autonomous executes planned tasks, taking scripted behaviors and autonomously converting them to waypoint and sensor plans for the unmanned assets.

Over the last 6 years, SAIC has been working with CERDEC and AMRDEC to introduce Battle Command aids supporting (semi) autonomous execution and collaboration of unmanned assets. This paper presents an operational context and a distributed command and control architecture aiming to reduce workload and increase operational efficiency pertaining to mission and asset management. This architecture has been implemented and demonstrated in field tests and as part of FY'09 C4ISR OTM testbed.

7694-28, Session 6

Heterogeneous sensor networks: a bio-inspired overlay architecture

J. A. Burman, Teledyne Scientific Co. (United States); J. P. Hespanha, U. Madhow, D. J. Klein, Univ. of California, Santa Barbara (United States); T. Pham, U.S. Army Research Lab. (United States); J. T. Isaacs, S. Venkateswaran, Univ. of California, Santa Barbara (United States)

A team consisting of Teledyne Scientific Company, the University of California at Santa Barbara and the Army Research Lab is developing technologies in support of automated data exfiltration for heterogeneous battlefield sensor networks as part of a US Army contract with the Institute for Collaborative Biotechnologies (ICB). Uninhabited air vehicles (UAV) provide an effective means to autonomously collect data from a sparse network of unattended ground sensors (UGSs). In addition to providing a communication infrastructure and a mechanism for implicit synchronization of sensors, UAVs can also be used to reduce the system reaction time by generating autonomous collection routes that are data-driven. Bio-inspired techniques for search will provide a novel strategy to detect, capture and fuse data across heterogeneous sensor networks. This can be achieved by avoiding situations in which several collectors simultaneously attempt to collect data from the same UGS. A fast and accurate method has also been developed to localize an event by fusing data from a sparse number of UGSs and involves the solution of a non-convex quadratic programming problem. A unique acoustic event classification algorithm was also developed based on using swarm

optimization to classify events. Very high classification accuracies were achieved using the swarm optimization method. The system was initially implemented using a high level simulation environment with a flight simulator to emulate a UAV collector. The high level simulation was extended by replacing the flight simulator with a real UAV and the architecture was tested in the field.

7694-29, Session 6

Optimal placement of multiple types of communicating sensors with availability and coverage redundancy constraints

S. Vecherin, U.S. Army Cold Regions Research and Engineering Lab. (United States) and New Mexico State Univ. (United States); D. K. Wilson, U.S. Army Cold Regions Research and Engineering Lab. (United States); C. L. Pettit, U.S. Naval Academy (United States)

Determination of an optimal configuration (numbers, types, and locations) of a sensor network is an important practical problem. In most applications, complex signal propagation effects and inhomogeneous coverage preferences lead to an optimal solution that is highly irregular and nonintuitive. The general optimization problem can be strictly formulated as a binary linear programming problem. Due to combinatorial nature of this problem, however, its strict solution requires significant computational resources (NP-complete class of complexity) and is unobtainable for large spatial grids of candidate sensor locations. For this reason, a greedy algorithm for approximate solution was recently introduced [S. N. Vecherin, D. K. Wilson, and C. L. Pettit, "Optimal sensor placement with terrain-based constraints and signal propagation effects," Unattended Ground, Sea, and Air Sensor Technologies and Applications XI, SPIE Proc. Vol. 7333, paper 73330S (2009)]. Here, further extensions to the greedy algorithm are presented to include other practical needs and constraints, such as sensor availability, coverage by multiple sensors when necessary for redundancy and tracking purposes, and wireless communication of the sensor information. Both communication and detection are considered in a probabilistic framework. Communication signal and signature propagation effects are taken into account when calculating probabilities of communication and detection. Comparison of approximate and strict solutions on reduced-size problems suggests that the approximate algorithm yields quick and good solutions, which thus justifies using that algorithm for full-size problems. Examples of three-dimensional outdoor sensor placement are provided using a terrain-based software analysis tool.

7694-30, Session 6

Unmanned vehicle technology for networked non-line-of-sight sensing applications

M. Gates, Louisiana Tech Univ. (United States); G. Pepper, Tennessee State Univ. (United States); A. K. Mitra, C. Hu, Air Force Research Lab. (United States); M. S. Zein-Sabatto, T. Rogers, Tennessee State Univ. (United States); R. R. Selmic, Louisiana Tech Univ. (United States); E. Hamdan, North Carolina A&T State Univ. (United States); M. Malkani, Tennessee State Univ. (United States)

We discuss the development, design, implementation, and demonstration of a robotic UGV (Unmanned Ground Vehicle) system for networked and non-line-of-sight sensing applications. Our development team is comprised of AFRL Summer Interns, University Faculty, and Personnel from AFRL. The system concept is based on a previously published technique known as "Dual-UAV Tandems for Indirect Operator-Assisted Control". This architecture is based on simulating a Mini-UAV Helicopter with a building-mounted camera and simulating a low-flying QuadRotor Helicopter with a Robotics UGV. The Robotics UGV is fitted with a

custom-designed sensor boom and a surrogate chem/bio (Carbon Monoxide) PCB sensor extracted from a COTS (Commercial-Off-The-Shelf) product. The CO Sensor apparatus is co-designed with the sensor boom and is fitted with a transparent covering for protection and to promote CO (surrogate chem/bio) flow onto the sensor.

The philosophy behind this non-line-of-sight system is to relay video of the UGV to an Operator station for purposes of investigating "Indirect Operator-Assisted Control" of the UGV via observation of the relayed EO Video at the Operator Station. In addition, this low-cost approach to networked sensing provides a "poor man's sensor fusion" in the sense that the in-house custom-designed analog 10-segment BAR Code display that is mounted on the body of the UGV is automatically overlayed onto the relayed EO Video.

For purposes of collecting scientific data with this system, we developed a Test (Data Collection) Matrix with following three parameters: 1. Chem/Bio Detection Level with Side-Looking Sensor Boom and Slowly Traversing UGV 2. Chem/Bio Detection Level with Panning Sensor Boom and Slowly Traversing UGV 3. Chem/Bio Detection Level with Forward-Looking Sensor Boom and Operator-Assisted Steering Based on Onboard Wind Vane Readings of UGV display that is Overlayed Onto Relayed Video. In addition to reporting the trends and results of analysis with regard to data collected with this Test Matrix, we discuss potential approaches to upgrading our networked robotics UGV system and also introduce the concept of "swapping sensors" with this low-cost networked sensor concept.

7694-31, Session 6

High-performance, miniature RF transceivers for energy aware UGSS

M. E. Barr, L. Webster, D. Maldonado, L-3 Communications Nova Engineering (United States)

The effectiveness of an Unattended Ground Sensor System (UGSS) can often be directly attributed to the robustness of its communications link. In legacy UGSS, the comms link provides a sensor's exfiltration path and, in some systems, an inbound link for sensor control and reconfigurability. In emerging UGSS, the comms provides a networked connection among the sensors for distributed processing, data fusion, or to improve the system's anti-jam performance. All of these applications require a high-performance transceiver that provides the requisite connectivity while supporting extended missions on small batteries.

This paper describes L-3 Nova's mNet family of miniature networked transceivers providing high data rate (500 kbps) networked connectivity. Unlike many COTS radios operating only in the 900 MHz or 2.4 GHz bands, the mNet offers added flexibility by providing coverage from 300 MHz to 2.48 GHz. This enables users to tailor the system for each deployment: low UHF, ideally suited for ground propagation, or 2.4 GHz when minimum profile antennas are required. mNet offers low power sleep modes and provides full software control of data rates, modulation settings and RF power levels. The on-board LNA and PA can be enabled to increase communication range or disabled to conserve power. The mNet utilizes ad-hoc mesh networking to form a collaborative network of radios supporting a common mission. These capabilities allow the system designer to dynamically optimize transceiver performance and battery consumption.

L-3 Nova offers a variety of mNet implementation options; some units are no larger than a coin.

7694-32, Session 6

Network of acoustic sensors for the detection of weapons firing: tests for the choice of individual sensing elements

P. Naz, S. Hengy, P. Hamery, Institut Franco-Allemand de Recherches de Saint-Louis (France); C. R. Marty, La Délégation Générale pour l'Armement (France)

This paper describes the comparison of various sensing elements that can be integrated in acoustic arrays being used for the detection of weapons firing. Experimental measurements of sound waves obtained using some of these elements in Unattended Ground Sensors are presented for snipers, mortars or artillery guns. These results have been obtained with the sensors deployed by the French-German Research Institute of Saint-Louis (ISL) during various tests like the last NATO/RTO/SET-093 Joint Field Experiment conducted in 2008 on the theme of "Acoustic Detection of Weapon Firing".

The emphasis will be put on the characteristics of the sensing elements needed to detect and classify the Mach wave generated by a supersonic projectile and the muzzle wave generated by the combustion of the propulsion powder. Tests with new sensors have been organized in laboratory conditions in order to complete the previous results.

Example of a wearable system considered to improve the soldier awareness of the surrounding threats will illustrate our topic: This realization consists in a network of three helmets integrating an acoustic array for the detection and localization of snipers.

7694-33, Session 6

Mobile optical detection system for counter surveillance

L. C. Sadler, T. A. Alexander, U.S. Army Research Lab. (United States)

There exists a current need to rapidly and accurately identify the presence and location of optical imaging devices used in counter-surveillance activities against U. S. troops deployed abroad. The locations of devices employed in counter-surveillance activities can be identified through detection of the optically augmented reflection from these devices. To address this need, we have developed a novel optical augmentation sensor, the Mobile Optical Detection System (MODS), which is uniquely designed to identify the presence of optical systems of interest. The essential components of the sensor are three, spectrally diverse diode lasers (1 ultraviolet/2 near-infrared) which are integrated to produce a single multi-wavelength interrogation beam and a charge-coupled-device (CCD) receiver which is used to detect the retroreflected, optically augmented beam returned from a target of interest. The multi-spectral diode laser illuminator and digital receiver are configured in a pseudo-monostatic arrangement and are controlled through a customized computer interface. By comparison, MODS is unique among OA sensors since it employs a collection of wavelength-diverse, continuous-wave (CW) diode laser sources which facilitate the identification of optical imaging devices used for counter-surveillance activities. In addition, digital image processing techniques are leveraged to facilitate improved clutter rejection concomitant with highly-specific target location (e.g., azimuth and elevation). More, the digital output format makes the sensor amenable to a wide range of interface options including computer networks, eyepieces and remotely-located displays linked through wireless nodes.

7694-34, Session 6

Implementation of utility based resource optimization protocols on ITA sensor fabric

S. Eswaran, Pennsylvania State Univ. (United States)

Utility-based cross-layer optimization is a valuable tool for resource management in mission-oriented wireless sensor networks (WSN). The benefits of this technique include the ability of take application- or mission-level utilities into account and to dynamically adapt to the highly dynamic environment of tactical WSNs. Recently, we developed a family of distributed protocols which optimally adapts the bandwidth and energy usage in mission-oriented WSN to maximize the total utility of the network, under various interesting scenarios such as the presence of (i) many-to-many flows competing for bandwidth, (ii) mission priorities and minimum utility requirements that have to be met, (iii) in-network

processing where forwarding nodes can adaptively compress data to the optimal levels, and (iv) lifetime requirements where the network must last for a certain period of time during which the utility is optimized. In this paper, we illustrate the practical applicability of this family of protocols in tactical networks by implementing one of them (viz., utility-based bandwidth allocation) on a real-time 802.11b network using a middleware called the ITA Sensor Fabric for communication. The ITA Sensor Fabric, which was developed as part of the International Technology Alliance, is a popular pub/sub-based communication infrastructure that was built to primarily to address the unique set of challenges resulting from the diverse sensor types and networking technologies commonly used in tactical WSNs. Through this implementation, we (i) study the practical challenges arising from the implementation and (ii) provide a proof of concept regarding the applicability of this family of protocols for efficient resource management in tactical WSNs amidst the heterogeneous and dynamic sets of sensors, missions and middle-ware.

7694-35, Session 7

Compact networked radars for Army unattended ground sensors

E. D. Adler, E. A. Viveiros, R. Wellman, J. Clark, D. A. Wikner, U.S. Army Research Lab. (United States); J. L. Kurtz, Univ. of Florida (United States)

Long-range, ground surveillance radars are large and consume a lot of power. Yet when they are properly placed on the battlefield, they can provide several kilometers of useful tactical information to the unit action commander. An alternative to this scenario is to deploy a network of compact radars that consume little power and can wirelessly report back to a base station to provide moving target indications on the battlefield. The Army Research Laboratory is in a partnership with the University of Florida - Electronics Communications Laboratory to develop compact radar technology and demonstrate that it is scalable to a variety of ultra-lightweight platforms (<10 lbs) to meet Army mission needs in persistent surveillance, unattended ground sensor (UGS), unmanned system, and man-portable sensor applications. The advantage of this compact radar is its steerable beam technology and relatively long-range capability compared to other small, battery-powered radar concepts. This paper will review the ongoing development of the sensor and presents a sample of the collected data thus far.

7694-36, Session 7

Profiling system design tradeoffs using the sparse detector sensor model

A. L. Robinson, C. E. Halford, The Univ. of Memphis (United States); R. B. Sartain, U.S. Army Research Lab. (United States)

This paper demonstrates that the tradeoffs of a profiling system design can be aided by the use of the sparse detector sensor model. The authors expect to include a trade space that considers detector type, input aperture size, target conspicuity and range.

7694-37, Session 7

A passive IR UGS called SPOT (silhouette profiling optical tripwire)

R. G. Rosemeier, F. Jin, K. Jia, R. Province, H. Wijaya, S. Vishnyakov, V. Stanislavsky, S. B. Trivedi, Brimrose Corp. of America (United States)

see above

7694-38, Session 7

Profiling sensor classification algorithm implementation on an embedded controller

R. K. Reynolds, D. J. Russomanno, S. K. Chari, C. E. Halford, The Univ. of Memphis (United States)

A proof-of-concept, active near-IR sensor with a sparse detector array has been shown to be a feasible approach to a low-cost unattended ground sensor for classifying moving objects such as humans, animals, or vehicles. The sensor produces a crude image or silhouette. This paper provides a feasibility analysis and details of implementing the classification algorithm on an embedded controller that is packaged with a prototype version of the sensor.

7694-39, Session 7

Mission specification and control for unmanned aerial and ground vehicles for indoor target discovery and tracking

P. Ulam, Z. Kira, R. C. Arkin, T. R. Collins, Georgia Institute of Technology (United States)

This paper describes ongoing research by Georgia Tech into the challenges of tasking and controlling heterogeneous teams of unmanned vehicles in mixed indoor/outdoor reconnaissance scenarios. These platforms are specifically geared towards microautonomous systems as part of ARL's MAST CTA program, although larger surrogate platforms are used for preliminary testing. In the scenarios that serve as the focus of this paper, an unmanned aerial vehicle is used to first scout the exterior of a target building, discover an entrance point, and then utilize that ingress to locate a target of interest. Once the target has been identified, the aerial vehicle then guides the team of ground vehicles into the building and into the proximity of the target of interest using a controlled formation. Finally, when contact has been made, the ground vehicles form a mobile, distributed sensor network suitable for intelligence gathering, including visual SLAM for reconnaissance.

We outline the tools and techniques necessary for an operator to specify, execute, and monitor such missions. The autonomous behaviors developed in support of these collaborative target identification and tracking scenarios are presented. The mission specification framework used for the purposes of intelligence gathering during mission execution is first demonstrated in simulations involving a team of a single autonomous rotorcraft and six ground-based robotic platforms. Preliminary results including robotic hardware in the loop are also provided.

7694-40, Session 7

The layered sensing operation center: a modeling and simulation approach to developing complex ISR networks

M. Lenzo, S. Mott, B. K. Preiss, C. Curtis, M. McClure, Air Force Research Lab. (United States)

The United States Air Force understands that traditional views of Intelligence, Surveillance, and Reconnaissance (ISR) need to adapt, and new capabilities need to be acquired to meet the constantly changing landscape of global warfare. To meet this challenge, the Air Force Research Laboratory (AFRL) is developing a unifying construct of "Layered Sensing" which will provide military decision-makers at all levels with the timely, actionable, and trusted information necessary for complete battlespace situational awareness. Layered Sensing is characterized by the appropriate combination of sensors/platforms (including those for persistent sensing), infrastructure, and exploitation capabilities to enable this situational awareness.

To achieve the Layered Sensing vision, AFRL is pursuing a Modeling & Simulation (M&S) strategy through the Layered Sensing Operations Center (LSOC). An experimental ISR system-of-systems testbed, the LSOC integrates DoD standard simulation tools with commercial, off-the-shelf (COTS) gaming technology for rapid development and enhanced visualization. In an effort to remain as flexible and cost effective as possible, the LSOC implements a non-proprietary, open-architecture framework with well-defined interfaces. This will incentivize transition of current ISR performance models to an object-oriented software design for increased reuse and consistency. In so doing, the LSOC will enable sensor architecture and subcomponent analysis, operator behavioral analysis, and ISR asset mission analysis. This paper will present the LSOC's development and implementation thus far as well as provide a summary of the lessons learned and future plans for the LSOC.

7694-41, Session 7

Pheromone-based coordination strategy to static sensor on the ground and unmanned aerial vehicles carried sensors

E. Pignaton de Freitas, Halmstad Univ. (Sweden); T. Heimfarth, Univ. Federal de Lavras (Brazil); A. Morado Ferreira, Instituto Militar de Engenharia (Brazil); C. E. Pereira, F. Rech Wagner, Univ. Federal do Rio Grande do Sul (Brazil); T. Larsson, Halmstad Univ. (Sweden)

A current trend that is gaining strength in the wireless sensor network area is the use of heterogeneous sensor nodes, in order to fulfil the requirements of sophisticated emerging applications, such as area surveillance systems. One of the main concerns when developing such sensor networks is how to provide coordination among the heterogeneous nodes, in order to enable them to efficiently respond the user needs. This study presents an investigation of strategies to coordinate a set of static sensor nodes on the ground with wirelessly connected Unmanned Aerial Vehicles (UAVs) carrying a variety of sensors, in order to provide efficient surveillance over an area of interest. The sensor nodes on the ground are set to issue alarms on the occurrence of a given event of interest, e.g. entrance of a non-authorized vehicle in the area, while the UAVs receive the issued alarms and have to decide which one is the most suitable to handle the issued alarm.

Two problems are focused in this study: the first is the alarm delivering to the UAVs while the second is the decision about which UAV will be responsible to handle the alarm. The proposal consists of a pheromone-based method to deliver alarms to the most suitable UAVs, considering a set of parameters to compute the utility in employing a given UAV to handle a certain target. This approach addresses the two problems by driving the alarm delivering to the most suitable UAV. Simulation results present indications of the efficiency of this proposal.

7694-42, Session 7

Exploiting segment summarization and cooperative storage for sensor data collection by mobile collectors

A. Misra, Telcordia Technologies, Inc. (United States); T. F. La Porta, The Pennsylvania State Univ. (United States)

This paper describes an architecture, called FIRMA, for efficient data collection by unmanned mobile collector nodes (e.g., UAVs/UGVs) from a deployed, heterogeneous, terrestrial sensor network. With the increasing data rates of sophisticated sensors (e.g., acoustic or video) and the potentially short-duration intermittent connectivity to a mobile collector, a major challenge is to preferentially transfer the right subsets of sensor data streams possessing high mission utility. FIRMA's first innovation is to have sensor nodes initially transfer locally-computed short segment summaries to the mobile collector, with such summaries describing appropriate features of the underlying data (e.g., spectral coefficients

of acoustic samples). The mobile collector then determines the relative utility of different segments, and subsequently employs several enhancements to the Network Utility Maximization (NUM) paradigm (developed in the NIS-ITA project) to regulate the concurrent transmission of multiple sensor stream segments over bandwidth-constrained wireless links. Additionally, the NUM framework must also incorporate the stochastic uncertainty in both the duration for which the network topology remains constant and in the quality of the wireless links, caused by the autonomous movement trajectory of the mobile collector. Our second innovation is to utilize cooperative and distributed sensor data storage among heterogeneous nodes as a means for reducing the duration of stream transfers. We propose and evaluate means by which the sensor data is proactively migrated to more capable nodes, which are predicted to possess better transfer paths or longer duration connectivity to the mobile collector.

7694-43, Session 7

Game theoretic approach to cooperative search with intelligent target

D. Shen, G. Chen, DCM Research Resources, LLC (United States); E. P. Blasch, K. D. Pham, Air Force Research Lab. (United States); H. Chen, Univ. of New Orleans (United States)

The goal of effective constellation management is to organize and control a collection of available platforms and sensors in a manner that maximizes one or more desirable metrics. This paper formulates the sensor constellation as a cooperative search problem where one or more evasive targets can hide in a subset of discrete cells. Cooperative searchers have to allocate the effort among these cells to maximize the target detection probability. We extend our previous two-person zero-sum search allocation game model where the target wants to hide from the searcher to general zero-sum case where the target has the capability of countermeasure. We implemented the algorithm in a UAV ISR scenario and compared our method with random search algorithm. Based on our study, we found that our search game algorithm is better than random search algorithm in the following two aspects: 1) search game algorithm has larger detection probabilities; and 2) search game algorithm uses the search resource budget in a more effective way as seen from larger cumulative detection probability being defined as the detection probability within the first 5 stages.

7694-44, Session 7

Real-time geo-registered steerable video generation

P. Maenner, S. L. Dockstader, ITT Visual Information Solutions (United States); R. Shuler, B. V. Brower, M. F. Pellechia, ITT Corp. (United States)

In this paper we present a new approach to the real-time generation and dissemination of steerable video chips from large volume motion imagery streams. Traditional large frame motion imagery streaming and dissemination systems employ JPEG 2000 (J2K) compression and associated JPEG 2000 Interactive Protocol (JPIP) streaming to encode and deliver images over varying bandwidth communication channels. While J2K and JPIP technologies are suitable for many large frame motion imagery applications, they often struggle to satisfy the needs of certain low power, low bandwidth users. The J2K format does not currently support inter-frame compression and, therefore, cannot target the lowest bandwidth motion imagery users. Additionally, J2K decompression and JPIP processing both consume more computational resources than low-end client systems often have available. This is especially true for handheld and thin-client devices. We address these issues by integrating region-of-interest J2K compression and JPIP streaming with MPEG-2 and H.264 video compression technology, taking advantage of the ubiquitous hardware acceleration and client ingest support for these full motion video product formats. The

proposed architecture maintains all the benefits of incorporating a J2K archival format, while also boasting the ability to disseminate J2K regions-of-interest and low resolution overviews to an even greater number of simultaneous clients. We illustrate a real-time integration and implementation of these technologies and show how they can be used to enable interactive and automated tracking and dissemination of multiple moving objects from wide area persistent surveillance motion imagery.

7694-45, Session 8

A flexible data fusion architecture for persistent surveillance using ultra-low-power wireless sensor networks

J. Hanson, K. L. McLaughlin, T. J. Sereno, Jr., SAIC (United States)

We have developed a flexible, target-driven, multi-modal, physics-based fusion architecture that efficiently searches sensor detections for targets and rejects clutter while controlling the combinatoric problems associated with large networks. Distributed networks of small, ultra-low power, unattended sensors have the potential to address a wide variety of needs for persistent surveillance in remote areas. Such networks can be standalone or used to trigger higher-power resources, such as imagers, for improved characterization. The informational constraints (both processing and bandwidth) imposed by very long lifetimes make the system vulnerable to false alarms and return ambiguous individual sensor results. In addition, mission goals vary substantially from project-to-project in terms of targets-of-interest, required characterization, acceptable latency, and false alarm rates, so a fusion architecture needs flexibility to match performance trade-offs with mission requirements.

We illustrate our data fusion architecture with case studies including border surveillance, base security, and infrastructure protection. In these studies, we deployed multi-modal sensor nodes - including geophones, magnetometers, accelerometers and PIR sensors - with low-power processing algorithms and low-bandwidth wireless mesh networking to create networks capable of multi-year operation. The results show high sensitivities and low false alarm rates for a variety of environments and targets.

7694-46, Session 8

Multi-asset control, sensor fusion, and information sharing through a centralized operator station

D. Gerlock, Honeywell, Inc. (United States)

As the number and variety of sensing and monitoring assets grows, the need for a centralized means of controlling and disseminating the crucial information from these assets grows with it. Over the past 5 years Honeywell has created a software application known as the Network-Enabled Operator Station (NEOS) to answer this need. NEOS has been developed from the ground up to be an open-architecture solution which integrates a variety of assets, communications systems and protocols, and data sharing techniques. It is designed with a common plugin architecture to easily accommodate new hardware and behaviors. NEOS facilitates all aspects of discovery, monitoring, and control of multiple assets; fusion of data from disparate sources; automated sharing of information; and mapping of triggers and actions to automate asset responses to sensor detections or other data inputs. The ultimate goals are to increase situational awareness and interoperability, reduce operator workload through automated behaviors and data sharing, and to provide a single, coherent tactical picture for the user. This paper will explain the genesis, capabilities, and benefits of NEOS in greater detail.

7694-47, Session 8

Sensor fusion for ISR assets

T. Damarla, U.S. Army Research Lab. (United States)

Sensor fusion of ISR will be presented in order reduce the bandwidth. An application will be described to high light the issues involved in sensor fusion for ISR and the sensor fusion approachs and their relative merits.

7694-48, Session 8

Services oriented architecture (SOA)-based persistent ISR simulation system

R. Cheng, DCM Research Resources, LLC (United States); E. P. Blasch, K. D. Pham, Air Force Research Lab. (United States); G. Chen, D. Shen, DCM Research Resources, LLC (United States); H. Chen, Univ. of New Orleans (United States)

In the modern networked battlefield, network centric warfare (NCW) scenarios need to interoperate between shared resources and data assets such as sensors, UAVs, satellites, ground vehicles and command and control (C2/C4I) systems. By linking and fusing platform routing information, sensor exploitation results, and databases (e.g. Geospatial Information Systems [GIS]), the shared situation awareness and mission effectiveness will be improved. Within the information fusion community, various research efforts are looking at open standard approaches to composing the heterogeneous network components under one framework for future modeling and simulation applications. By utilizing the open source services oriented architecture (SOA) based sensor web services, and GIS visualization services, we propose a framework that ensures the fast prototyping of ISR system simulations to determine asset mix for a desired mission effectiveness, performance modeling for sensor management and prediction, and user testing of various scenarios.

7694-49, Session 8

A location-based architecture for fusion of disparate data sources

P. Scheffel, McQ, Inc. (United States)

McQ has developed an architecture for fusing information from widely disparate data sources, based on georeferenced heatmap style translations of incoming data. The architecture takes into account not only activity information, but also the capabilities of the data sources for that area. This inclusion of knowledge gathering potential along with gathered knowledge helps combat selection bias, allowing better conclusions about scenarios with sparse information.

7694-50, Session 8

Flexible application for consolidation and presentation of intelligence, surveillance, and reconnaissance data

D. Garrison II, S. Janis, H. M. Sasaki, Harris Corp. (United States)

Unattended Ground Sensors have found widespread usefulness in force and asset protection, border patrol and, drug enforcement. In recent years their application has extended into ground and air surveillance providing additional data from disparate networked intelligence, surveillance and reconnaissance (ISR) resources. The consolidation of this data and effective presentation through software applications efficiently communicates critical information that helps the analyst support persistent surveillance missions. This paper presents the interface of one such flexible application with an emphasis on its presentation elements and information content.

SPIE
Defense,
Security+Sensing

7694-51, Session 8

Platform routing and data fusion technologies for cooperative ISR - fmCortex

J. Carter, A. Pernicka, IAVO Research and Scientific (United States); J. Llinas, M. Karwan, J. L. Crassidis, CUBRC (United States)

This paper reports on an Air Force Research Laboratory funded research and development effort to provide optimal platform routing, dynamic resource management and fusion of incongruent ISR assets with emphasis on the integration and networking of those assets into a cooperative system. The primary objective is to concentrate on the optimal real-time use of a combination of cooperative wide-body and multi-UAV systems to offer the positive and complementary benefits of improved ISR routing and data fusion resulting in reliable actionable intelligence. This demands progressive algorithmic techniques and methods embedded in theoretically innovative approaches. In the evolving approach, methods from mathematical programming, navigation technologies, distributed fusion, and stochastic adaptive control have been developed and integrated to provide a solution that addresses these needs while affording a dynamic and extensible architecture - one that could be applied to a variety of military and commercial applications. In addition, the architecture in which these methods interoperate also includes techniques developed within the program to account for a variety of real-world effects typically omitted in such systems, such as real-world platform navigational and flight-behaviors, weather effects, and no-fly-zone effects. Techniques for semi-automated development of these composite methods have also been built, and allow for efficient formal integration of a wide variety of mission/task types.

Conference 7695: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVI

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7695-01, Session 1

Continuum fusion: a new methodology for creating hyperspectral detection algorithms

A. P. Schaum, U.S. Naval Research Lab. (United States)

Many detection algorithms popular in hyperspectral sensing trace their theoretical origins to either a likelihood ratio test or a generalized likelihood ratio (GLR) test. Because the former requires perfect knowledge of the relevant statistics, realistic problems are frequently posed as composite hypothesis (CH) tests, using probability density functions whose forms are known, but which depend on parameters with unknown values. For these the GLR recipe can always produce algorithms, examples of which are the linear matched filter, the Kelly-RX anomaly detector, and Scharf subspace detectors. Thousands of technical papers in hyperspectral and other fields have invoked the GLR since the early 20th century. Here we propose a new methodology for producing detection algorithms that can be applied to any CH problem. Instead of maximizing probability density functions for alternative hypotheses for each test sample, the FLR (fused likelihood ratio) method integrates a continuum of optimal methods corresponding to each allowed parameter value. The method of fusion comes in many flavors, each with its own partial differential equation. Several example hyperspectral problems are defined that can be solved with purely geometrical reasoning. It is also shown in general that among the flavors of FLR solutions to any given CH problem, one always exists that is at least as good as the GLR solution.

7695-02, Session 1

Sparse subspace target detection for hyperspectral images

Y. Chen, The Johns Hopkins Univ. (United States); N. M. Nasrabadi, U.S. Army Research Lab. (United States); T. D. Tran, The Johns Hopkins Univ. (United States)

In this paper, we propose a new sparsity-based algorithm for automatic target detection in hyperspectral images (HSI). This algorithm is based on the concept that a pixel in HSI lies in a low-dimensional subspace and thus can be represented by a sparse linear combination of the training samples. The sparse representation (a sparse vector representing the selected training samples) of the test sample can be recovered by solving an l0-norm minimization problem. With the recent development of Compressed Sensing theories, the minimization problem can be recast as a linear programming or solved efficiently by a greedy pursuit algorithm. Once the sparse vector is obtained, the class of the test sample can be directly determined by the behavior of the vector on reconstruction. In addition to the constraints on sparsity and reconstruction accuracy, we also exploit the fact that HSI are usually smooth in that neighboring pixels have a similar spectral characteristic. In our proposed algorithm, a smoothness constraint is also imposed by forcing the Laplacian of the reconstructed image to be zero in the minimization process. The proposed sparsity-based algorithm is applied to several hyperspectral images to detect targets of interest. Simulation results show that our algorithm outperforms the other HSI target detection algorithms, including the popular spectral matched filters, matched subspace detectors, and adaptive subspace detectors.

7695-03, Session 1

URCHIN: an RX-derivative accounting for anisotropies in whitened clutter

B. J. Daniel, A. P. Schaum, U.S. Naval Research Lab. (United States)

The most widespread methods of anomaly detection in hyperspectral imagery (HSI) are the RX algorithm and its variants (e.g. Subspace RX). RX is optimal for any unimodal elliptically contoured distribution (ECD), and it misinterprets any deviations from this model as true anomalies. Singleton outliers are by definition anomalous, but other RX detections can arise from less severe departures from the ECD, in the form of spectral "prominences." We describe a method that mitigates such persistent false alarms. We augment RX in a recursive process with truncated versions of the Adaptive Cosine Estimator (ACE), which is applied to RX exceedances that arise from prominences, bulges appearing in the whitened clutter distribution that indicate anisotropy. The ACE-augmented RX decision surface resembles a sea urchin.

7695-04, Session 1

Segmentation adaptive RX: an algorithm for spectral anomaly detection in a variety of measured-radiance conditions

A. V. Kanaev, Global Strategies Group (North America) Inc. (United States); J. Murray-Krezan, U.S. Naval Research Lab. (United States)

One of the persistently challenging problems for standard implementations of hyperspectral detection algorithms is automated detection of poorly illuminated, or otherwise low-reflectance objects in reflective-domain hyperspectral imagery. We present an algorithm specifically designed to handle a variety of reflectance and illumination conditions without assuming knowledge about the background spectra or detected-object spectra. Rather, the algorithm we employ, Segmentation Adaptive RX (SARX), relies on panchromatic segmentation of hyperspectral data into dark and bright clusters, based on the measured-radiance signal level, followed by applications of RX detection in spectral subspaces. We demonstrate the capability of SARX to detect spectrally anomalous objects in a variety of measured-radiance conditions.

7695-05, Session 1

Hyperspectral outlier detector based on conditional distributions

E. Lo, Susquehanna Univ. (United States)

An outlier detection algorithm for hyperspectral imaging based on likelihood ratio test is presented in this article. The null hypothesis tests if a test pixel is from the conditional distribution of the pixel given the background subspace and the alternative hypothesis tests if a test pixel is from the conditional distribution of the pixel given the target subspace. Using principal components for the complementary subspaces, a practical outlier detector is developed and is compared to conventional outlier detectors using VNIR hyperspectral imagery.

7695-06, Session 1

Improved outlier identification in hyperspectral imaging via nonlinear dimensionality reduction

C. C. Olson, J. M. Nichols, J. V. Michalowicz, F. Bucholtz, U.S. Naval Research Lab. (United States)

We combine two nonlinear dimensionality reduction techniques to reduce data requirements and improve outlier detection in hyperspectral imaging applications. Diffusion map is used to map a subset of pixels from the high-dimensional spectral space to a lower-dimensional manifold that retains a measure of distance between the selected pixels. This lower-dimensional manifold represents the background of the scene with high probability and selecting a subset of points reduces the computational overhead associated with the dimensionality reduction. The remaining pixels are mapped to the low-dimensional manifold by means of locally linear embedding. A distance measure is naturally computed for each new pixel as part of the embedding process and those that do not reside near the background manifold, as determined by a threshold, are identified as outliers. We discuss and compare classification and target detection within this framework as well as issues pertaining to background manifold updating when continuous image registration is required.

7695-07, Session 2

An overview of the Landsat Data Continuity Mission

J. R. Irons, NASA Goddard Space Flight Ctr. (United States); J. L. Dwyer, U.S. Geological Survey (United States)

The advent of the Landsat Data Continuity Mission (LDCM), currently with a launch readiness date of December, 2012, will see evolutionary changes in the Landsat data products available from the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center. The USGS initiated a revolution in 2009 when EROS began distributing Landsat data products at no cost to requestors in contrast to the past practice of charging the cost of fulfilling a request; that is, charging $600 per Landsat scene. To implement this drastic change, EROS terminated data processing options for requestors and began to produce all data products using a consistent processing recipe. EROS plans to continue this practice for the LDCM and will required new algorithms to process data from the LDCM sensors. All previous Landsat satellites flew multispectral scanners to collect image data of the global land surface. Additionally, Landsats 4, 5, and 7 flew sensors that acquired imagery for both reflective spectral bands and a single thermal band. In contrast, the LDCM will carry two pushbroom sensors; the Operational Land Imager (OLI) for reflective spectral bands and the Thermal InfraRed Sensor (TIRS) for two thermal bands. EROS is developing the ground data processing system that will both calibrate and correct the data from the thousands of detectors employed by the pushbroom sensors and that will also combine the data from the two sensors to create a single data product with registered data for all of the OLI and TIRS bands.

7695-08, Session 2

Compact infrared hyperspectral imaging polarimeter

J. Craven, M. W. Kudenov, D. Stapelbroek, E. L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States)

A compact SWIR/MWIR infrared hyperspectral imaging polarimeter (IHIP) is currently under development at the Optical Detection Lab at the University of Arizona. The sensor uses a pair of sapphire Wollaston prisms and high order retarders to form an imaging birefringent Fourier transform spectropolarimeter. Polarimetric data are acquired through the use of channeled spectropolarimetry to modulate the interferogram with the Stokes parameter information. The two dimensional interferogram is Fourier filtered and reconstructed to recover the complete Stokes vector across the image. The IHIP operates over a +/-5 degree field of view and uses the dual-scan false signature reduction technique to suppress polarimetric aliasing artifacts. We present current instrument development progress, initial laboratory results, and our plan for future work.

7695-09, Session 2

An airborne hyperspectral target detection system with real-time processing

T. Skauli, T. V. Haavardsholm, I. Kåsen, G. Arisholm, A. Kavara, T. O. Opsahl, A. Skaugen, Norwegian Defense Research Establishment (Norway)

Hyperspectral remote sensing from airborne platforms has significant potential for use in many military applications. To enable operational experimentation and exploration, a hyperspectral technology demonstrator system has been developed at FFI, the Norwegian defence research establishment.

The main sensor in the system is a pushbroom hyperspectral imager for the visible and near-infrared spectral range with 1600 pixels across track (NEO HySpex VNIR-1600) supplemented by an 8192-pixel panchromatic imager (Dalsa Piranha2 8k). An optional third camera can also be accommodated, either a hyperspectral camera for the short wave infrared (SWIR) spectral range or a thermal imager. For navigation, the system employs a GPS receiver and an inertial sensor, synchronized with the cameras through custom built electronics, and sensor imagery is georeferenced in real time.

The hyperspectral image data are processed in a PC with a multicore Intel processor and an Nvidia graphics processing unit (GPU). A nonlinear pipeline processing chain is built using a software framework optimized for large sustained data rates. The framework provides for flexible implementation of processing algorithms exploiting the multicore processor and GPU. The initial version of the system performs spectral anomaly detection based on normal mixture models for representation of the background. Imagery and target detection results are visualized using a customized version of an operational geospatial visualization software (Kongsberg exploitation station).

The system is flown in a specially modified Cessna 172 light aircraft based close to FFI, in collaboration with the Norwegian voluntary flying corps. This arrangement provides for very convenient and cost-effective operation of the system.

7695-10, Session 2

Hyperspectral sensor for analysis of gases in the atmosphere (HYGAS)

R. Harig, P. Rusch, Technische Univ. Hamburg-Harburg (Germany); S. M. Sabbah, J. Gerhard, Sigma ElectroOptics GmbH (Germany)

Remote sensing by infrared spectroscopy allows identification and quantification of atmospheric gases as well as airborne pollutants. An application of the method that has gained increased interest in recent years is remote sensing of hazardous gases. If hazardous compounds are released into the atmosphere, for example in the case of a chemical accident, emergency response forces require information about the released compounds immediately in order to take appropriate measures to protect workers, residents, and the environment. A hyperspectral sensor allows identification and visualization of hazardous clouds in the atmosphere from long distances. The image of a cloud allows an assessment of the dimensions and the dispersion of a cloud. In addition, the source of a cloud may be located. A hyperspectral sensor based on an imaging Fourier-transform spectrometer with a focal plane array

detector is currently being developed in the framework of a collaboration project funded by the German ministry of research BMBF. Compared to conventional spectrometers, hyperspectral systems allow the use of spatial information in addition to spectral information. Thus, in order to achieve low limits of detection, algorithms that combine algorithms for spectral analysis and image analysis have been developed. In addition to the application of remote gas sensing, the system may be applied in other fields of research such as the detection of liquids and atmospheric measurements. In this work, the HYGAS system, the analysis algorithms, and first results of measurements are presented.

7695-11, Session 3

A scalable approach to modeling nonlinear structure in hyperspectral imagery and other high-dimensional data using manifold coordinate representations

C. M. Bachmann, T. L. Ainsworth, R. A. Fusina, U.S. Naval Research Lab. (United States)

In the last several years, we have developed an approach to modeling nonlinear structure in hyperspectral imagery using manifold coordinate representations [1][2][3]. This scalable approach to deriving an intrinsic coordinate system for the data has allowed us to develop a practical framework for processing large-scale remote sensing imagery in a variety of applications such as water column retrievals, e.g. bathymetry and bottom type [3], as well as land-cover [2] and anomaly finding. Along the way, we have improved modeling of the local curvature as a means of providing higher fidelity models [4][5]. Although the processing framework has been successful and is practical on a single-cpu workstation in a matter of hours, recent work described in another paper at this conference has focused on reducing the computational time from hours to minutes using GPU-based algorithms [6] in a cooperative effort between NRL and Celestech. This talk provides an overview of our algorithms and approach, discusses the scaling issues that we have overcome to develop a practical algorithm that can operate at typical remote sensing data volumes, and provides examples of applications using a number of different hyperspectral data sets.

[1] Bachmann, C. M., T. L. Ainsworth, and R. A. Fusina, 2005. "Exploiting Manifold Geometry in Hyperspectral Imagery," IEEE Trans. on Geoscience and Remote Sensing, 43(3):441-454.

[2] Bachmann, C. M., T. L. Ainsworth, R. A. Fusina, 2006. "Improved Manifold Coordinate Representations of Large Scale Hyperspectral Imagery," IEEE Trans. on Geoscience and Remote Sensing, 44(10): 2786-2803.

[3] Bachmann, C. M., T. L. Ainsworth, R. Fusina, M. Montes, J. Bowles, D. Korwan, D. Gillis, "Bathymetric Retrieval from Hyperspectral Imagery Using Manifold Coordinate Representations," IEEE Trans. Geoscience and Remote Sensing, March 2009, 47(3): 894-897.

[4] Bachmann, C. M., T. L. Ainsworth, R. A. Fusina, "Automated Estimation of Spectral Neighborhood Size in Manifold Coordinate Representations of Hyperspectral Imagery: Implications for Anomaly Finding, Bathymetry Retrieval, and Land Applications," Proc. IGARSS'08, Boston, MA, July 2008.

7695-12, Session 3

A high-speed implementation of manifold coordinate representations of hyperspectral imagery: a GPU-based approach to rapid nonlinear modeling

R. Topping, J. French, Celestech, Inc. (United States)

Working with the Naval Research Laboratory (NRL), Celestech has implemented advanced non-linear hyperspectral image (HSI) processing algorithms [1] optimized for Graphics Processing Units (GPU). These

algorithms have demonstrated performance improvements of nearly 2 orders of magnitude over optimal CPU-based implementations. The paper briefly covers the architecture of the NIVIDIA GPU to provide a basis for discussing GPU optimization challenges and strategies. The article then covers optimization approaches employed to extract performance from the GPU implementation of the NRL algorithms including memory utilization and process thread optimization considerations.

The article goes on to discuss strategies for deploying GPU-enabled servers into enterprise service oriented architectures. Also discussed are Celestech's on-going work in the area of middleware frameworks to provide optimized multi-GPU utilization and scheduling approach that supports both multiple GPUs in a single machine as well as across multiple machines, and GPU-enabled applications that provide advanced data visualization techniques for large hyperdimensional data sets.

This paper is a complimentary work to the paper submitted by NRL to this conference [2]. The NRL paper covers the algorithmic and theoretical basis for the HSI processing approach.

[1] Bachmann, C. M., T. L. Ainsworth, R. A. Fusina, 2006. "Improved Manifold Coordinate Representations of Large Scale Hyperspectral Imagery," IEEE Trans. on Geoscience and Remote Sensing, 44(10): 2786-2803.

[2] Bachmann, C. M., T. L. Ainsworth, R. A. Fusina, submitted. "A Scalable Approach to Modeling Nonlinear Structure in Hyperspectral Imagery and Other High-Dimensional Data Using Manifold Coordinate Representations," SPIE, Orlando, 2009.

7695-13, Session 3

An approach to use spatial information on neighborhood selection in nonlinear dimensionality reduction methods for hyperspectral imagery

N. Rey-Villamizar, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Dimensionality reduction is a key step in hyperspectral image processing. Linear and nonlinear methods have been proposed for this task. In general, nonlinear manifold learning methods such as Isomap, Local Linear Embedding, Laplacian and Hessian Eigenmaps are use to recover the low dimensional representation of an unknown nonlinear manifold for high dimensional data where it is important to retain the neighborhood structure of the manifold. Although these algorithms use different philosophies for recovering the nonlinear manifold, they all incorporate neighborhood information from each data point to construct a weighted graph having the data points as vertices. The data reduction is performed by eigen-analysis of this graph. The K-NN algorithm is the most widely used technique for neighbor selection. However, for hyperspectral images, this technique and others do not take into account the available spatial information. Here, we present a method that includes spatial and spectral information in neighbor selection for nonlinear dimensionality reduction (NLDR). The proposed method is compared to exiting methods, when combined with different NLDR methods. We present experimental results that show how the proposed method can improve classification performance.

7695-14, Session 3

Invariant recognition of 3D hyperspectral textures using spectral/spatial filters

G. E. Healey, T. Bau, Univ. of California, Irvine (United States)

We develop a method for the recognition of textures with three-dimensional structure in hyperspectral images.

Properties of a texture are captured by a feature vector that is generated by a bank of spectral/spatial Gabor filters.

Variation in the illumination and atmospheric conditions is modeled using a subspace of the feature vectors.

Since a large bank of filters is used, we develop methods for reducing the dimension of the feature vector that is used to represent a texture.

The goal of the dimension-reduction process is to optimize the discriminability of a set of textures.

We demonstrate the utility of the approach using experiments with hyperspectral textures of three-dimensional objects that are generated by DIRSIG over a range of conditions.

7695-16, Session 4

Accelerating a hyperspectral inversion model for submerged marine ecosystems using high-performance computing on graphical processor units

J. A. Goodman, Univ. de Puerto Rico Mayagüez (United States); D. Kaeli, D. Schaa, A. Yilmazer, Northeastern Univ. (United States)

Remote sensing of submerged marine ecosystems presents a challenging environment for information extraction algorithms, where physically based solutions commonly require complex, computationally intensive algorithms. The inherent variations in water depth, water properties, and surface waves all impact the measured remote sensing signal, and the strong absorption of light in water also limits the effective range of wavelengths available for analysis. An algorithm has been developed to address this multifaceted problem. The algorithm uses an integrated inverse semi-analytical optimization model and spectral unmixing scheme to derive water column properties, water depth and habitat composition from imaging spectroscopy data. In addition to testing and validation studies, work on this algorithm has also included improving its efficiency using the computing power of graphical processor units (GPUs). This improvement provides accelerated execution of the algorithm, and by leveraging more robust optimization routines, also facilitates increased accuracy in algorithm output. Harnessing this potential, however, requires a different paradigm for parallelizing algorithms than commonly utilized for approaches using multi-core central processing units. The GPU processing and memory architecture requires finer-grained parallelization of both the data and algorithms, and achieving significant acceleration requires algorithm-specific consideration for thread generation and data placement within the GPU. Initial results from implementing the algorithm on a single GPU indicate an order of magnitude improvement in performance can be achieved using this technology. We present an overview of the algorithm, provide example output, discuss the GPU parallelization approach, and illustrate the performance achievements that have been obtained using GPU technology.

7695-17, Session 4

Estimating canopy coverage via VNIR/SWIR hyperspectral detection methods

M. Z. Salvador, Logos Technologies, Inc. (United States); W. L. Nelson, National Geospatial-Intelligence Agency (United States); D. L. Rall, EOIR Technologies, Inc. (United States)

Canopy coverage is a significant factor in assessing the performance of target detection algorithms. This is true of electro-optical (EO), radar frequency (RF), light detection and ranging (LIDAR), multi/hyperspectral (MSI/HSI), and other remote sensing methods. This research compares traditional ground based methods of estimating canopy closure with estimates of canopy cover via spectral detection methods applied to VNIR/SWIR hyperspectral imagery. This paper uses canopy cover and canopy closure as defined by Jennings, et al. 1999.

In the Summer of 2009, a pushbroom VNIR/SWIR hyperspectral sensor

collected data over a forested region of the Naval Surface Warfare Center, Dahlgren Division, Virginia. This forested region can be best described as single canopy cover with multiple tree species. Hyperspectral imagery was collected over multiple days and at multiple altitudes in August and September, 2009. On the ground, densiometer measurements and nearly hemispherical photography were used to estimate canopy closure at 10 meter intervals across a 2500 m2 grid. Several spectral detection methods including vegetation indices, matched filtering, linear un-mixing, and distance measures, are used to calculate canopy coverage at varying ground sample distances and across multiple days. These multiple estimates are compared to the ground based measurements of canopy closure. Results indicate that estimates of canopy coverage via VNIR/SWIR hyperspectral imagery compare well to the ground based canopy closure estimates for this single canopy region. This would lead to the conclusion that it is possible to use airborne VNIR/SWIR hyperspectral alone to provide an accurate estimate of canopy coverage.

7695-18, Session 4

Hyperspectral object tracking using small sample size

D. S. Rosario, U.S. Army Research Lab. (United States); H. Kling, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

We address the movement-less object tracking problem. For a particular application, the challenges are: (i) No offline training allowed; (ii) objects of interest (targets) have a small sample size (e.g., less than 9); and (iii) the relative movement of targets cannot be used for tracking, since stationary targets are also of interest. We address these challenges by using hyperspectral (HS) imagery and proposing a simple algorithm. The algorithm exploits the mean and median of the unknown probability distribution function (PDF) controlling an initial target sample; the coarse estimates are used to measure a positive, negative, or none tendency of a third PDF feature: Skew. This is possible because both mean and median can be reasonably estimated using small sample sizes. A negative skew indicates a longer PDF left tail, i.e., the mean is lesser than the median; a positive skew indicates a longer PDF right tail, i.e., the mean is greater than the median; and a zero skew indicates a symmetric PDF about the mean, i.e., the mean is equal to the median. Thus, in spite of small sample sizes, the proposed method can estimate and use three orthogonal features (spectral mean, skew tendency and sign) in order to compare spectral samples of similar or distinct PDFs. Tracking HS targets is then possible using this algorithm to test a sequence of HS imagery, given that an initial cue of target samples is obtained early in that sequence by the user. Preliminary results are promising using a limited but challenging dataset.

7695-19, Session 4

Ship detection using hyperspectral imagery

M. J. Marin-Quintero, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Hyperspectral imaging sensors can be an important addition to an array of technologies employed to enhance maritime situational awareness. Since shipping lanes to major U.S. ports are well established and the U.S. Coast Guard now requires 96-hour port entry notification, an operational concept that uses space-based and land-based imaging sensors to help detect shipping anomalies would enable the timely deployment of other more tactical assets (e.g., patrol craft and Unmanned Aerial Vehicles) that could identify and investigate suspicious activity. This paper presents a survey of techniques for ship detection and tracking using spectral sensing and studies how hyperspectral imaging can be used for the identification of ships in open and coastal waters. The underlying hypothesis is that the high spectral resolution allows improved discrimination of the ship from its background even at the subpixel level. The paper presents results on applying different pixel and subpixel detection methods for this application and their

dependence on spatial resolution.

7695-20, Session 5

Spectral imagery collection experiment

J. M. Romano, U.S. Army Armament Research, Development
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Research Lab. (United States); V. Farley, Telops (Canada)

The Spectral and Polarimetric Imagery Collection Experiment (SPICE)
is a collaborative effort between the Army Armaments Research and
Development Engineering Center and the Army Research Laboratory that
is focused on the collection of mid-wave and long-wave infrared imagery
using hyperspectral, polarimetric, and broadband sensors.

The objective of the program is to collect a comprehensive database
of MWIR, LWIR, multispectral LWIR polarimetric, MWIR and LWIR
hyperspectral, and 35 and 94GHz Radar over the course of 1 to 2 years
to capture performance during a wide variety of weather conditions (fog,
rain, snow, etc...) and seasonal changes.

Using the Precision Armament Laboratory tower at Picatinny Arsenal,
the sensors will autonomously collect the desired data around the clock
at 500 and 1200m ranges. A number of surrogate 2S3 Self-Propelled
Howitzer targets will be positioned at different viewing perspectives in an
open field. To support the mission, all surrogate targets have been fitted
with thermal heating panels to mimic the 2S3 heat profile (engine deck,
gun tube, overhead compartment, and wheels) and are instrumented to
remotely record target temperatures.

This database will allow for: 1) Evaluation of hyperspectral and
polarimetric technologies; 2) Development of new sensors; 3) Understand
of signature variability under the different weather conditions; and 4)
Evaluation of fusing the different sensor modalities.

In this paper, we will present the SPICE data collection objectives,
the ongoing effort, the sensors that are currently deployed, and how
this work will assist researches on the development and evaluation of
sensors, algorithms, and fusion applications.

7695-21, Session 5

Longwave infrared hyperspectral imagery of a subpixel emplacement of a polyethylene plastic film: the 'plastic plume' as a gas-phase analog target

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States)

Acquiring ground-truth data of gaseous effluents simultaneously with the
collection of remotely sensed hyperspectral imagery (HSI) is an extremely
difficult, if not impossible, task. For rigorous algorithm development and
testing, precise ground-truth information is mandatory. Imprecise and/
or uncertain truth data will impede the development and refinement of
information-extraction tools and techniques for the remote sensing of
gases. In an attempt to generate well-truthed data, thin plastic films have
previously been assessed as gas-phase analog targets. With thin films,
material location, abundance, temperature, and subpixel distributions
can be well known, easily measured, and highly controlled. Large plastic
thin-films or 'plastic plumes' of polyethylene (PE) have been deployed in
past HSI data collection campaigns for which longwave infrared (LWIR)
airborne HSI data were acquired. The plastic films yielded spectral
signatures similar to those of gases and were demonstrated to be
viable analogs for gaseous effluents. Results of the analysis of those
data have been reported elsewhere [1]. The deployments of PE in those
collections yielded multi-pixel occurrences of a uniform, solid sheet.
Gases, however, may not always uniformly fill a pixel and the true three-
dimensional structure of a gas-phase plume may have voids through
which radiance from the background may pass unimpeded. A trial of the

plastic plume concept to model this scenario was warranted. Thus, in a
follow-on airborne LWIR HSI collection experiment recently completed
and discussed here, holes were cut in a large sheet of PE yielding a film
with 75% PE and 25% void space. The deployment of the sheet likewise
covered several pixels in the HSI data yielding a multi-pixel occurrence of
a subpixel quantity (75%) of the PE plastic film. PE film, air, and ground
temperatures were logged; spectral measurements of the background
were acquired and PE film transmissivity was measured in the laboratory.
The HSI data have been analyzed to yield plastic plume abundance and
temperature. The theoretical background supporting the use of plastic
films as gas analogs is discussed as are the results of the analysis of the
LWIR HSI airborne and ground-truth data of the 75% PE/25% void-space
plastic plume.

[1] Resmini, R.G., and Mitchell, H.J., 2008. On the use of thin plastic films
as gas-phase analog targets. IEEE International Geoscience and Remote
Sensing Symposium, 2008, 7-11 July, v. 4, pp. IV-577 to IV-580, doi:
10.1109/IGARSS.2008.4779787.

7695-22, Session 5

A new hyperspectral dataset and some challenges

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We present a new hyperspectral dataset that FOI will keep publicly
available. The hyperspectral data set was collected in an airborne trial
over the countryside. The spectral resolution was about 10 nm which
allowed registrations in 60 spectral bands in the visual and near infrared
range (390-960 nm). Objects with various signature properties were
placed in three areas: the edge of a wood, an open field and a rough
open terrain. Several overflights were performed over the areas. Between
the overflights some of the objects were moved, representing different
scenarios. Our interest is primarily in anomaly detection of man-made
objects placed in nature where no such objects are expected. The
objects in the trial were military and civilian vehicles, boards of different
size and a camouflage net. The size of the boards range from multipixel
to subpixel size. Due to wind and cloud conditons the stability and the
flight height of the airplane vary between the overflights, which makes the
analysis extra challenging.

The data is divided into test sets with known position of the objects and
blind test sets where it is possible to submit results and get a score. We
will keep a top list results on the internet page.

We have made basic analysis of the data set and present results from
some well known algorithms.

7695-23, Session 6

Sub-pixel radiometry: a three-part study in generating synthetic imagery that incorporates sub-pixel variation

S. Paul, A. A. Goodenough, S. D. Brown, C. Salvaggio, Rochester
Institute of Technology (United States)

A pixel, by definition, is the smallest item of information in an image. It
is a single (perhaps spectral) value that represents a spatial portion of
a scene. In any captured image, that single value is the result of many
factors including the composition of scene optical properties within the
projected pixel, the characteristic point spread function (or, equivalently,
modulation transfer function) of the system, and the sensitivity of the
detector element itself. This presentation examines the importance of
sub-pixel variability in the context of generating synthetic imagery for
remote sensing applications. The study was performed using the Digital
Imaging and Remote Sensing Synthetic Image Generation (DIRSIG) tool,
an established ray-tracing based synthetic modeler whose approach to
sub-pixel computations was updated during this project.

The study examines three aspects of sub-pixel variability of interest

to the remote sensing community. The first simply looks at sampling frequency relative to structural frequency in a scene and the effects of aliasing on an image. The second considers the task of modeling a sub-pixel target whose signature would be mixed with background clutter, such as a small, hot target in a thermal image. The final study looks at capturing the inherent spectral variation in even a single class of material, such as grass in hyperspectral imagery. Through each study we also demonstrate the capabilities of DIRSIG's sub-pixel algorithms and quantify improvements over previous approaches.

7695-24, Session 6

Full-spectrum cloudy scene simulation

R. L. Sundberg, S. C. Richtsmeier, Spectral Sciences, Inc. (United States); R. Haren, Air Force Research Lab. (United States)

The MCScene code, which is a high fidelity model for full optical spectrum (UV to LWIR) spectral image simulation, will be discussed and its features illustrated with sample calculations. The MCScene simulation is based on a Direct Simulation Monte Carlo approach for modeling 3D atmospheric radiative transport, as well as spatially inhomogeneous surfaces including surface BRDF effects. The model includes treatment of land and ocean surfaces, 3D terrain, 3D surface objects, and effects of finite clouds with surface shadowing. This paper will review the more recent upgrades to the model including the development of an approach for incorporating direct and scattered thermal emission predictions into the MCScene simulations. Sample calculations presented in the paper include a full optical spectrum simulation from the visible to the LWIR for a desert scene that includes a warm gas plume produced by a power generation plant. This scene was derived from an AVIRIS visible to SWIR spectral imaging data collect over the Virgin Mountains in Nevada. The data has been extrapolated to the thermal IR and a representative power plant model has been added to the scene. Other calculations include complex 3D clouds over urban and rural terrain.

7695-25, Session 6

Characterization of material reflectance variation through measurement and simulation

J. P. Kerekes, C. Hart, M. G. Gartley, B. D. Bartlett, Rochester Institute of Technology (United States); E. Nance, Raytheon Intelligence & Information Systems (United States)

The characterization of material reflectance properties is important in the analysis of hyperspectral and polarization imagery in material/object detection and identification applications, as well as the accurate physics-based forward simulation of such images. While much work has been done on the measurement of reflectance properties of man-made materials, much was done in the laboratory under ideal conditions. Real imagery, however, typically is of objects observed under less ideal conditions. Therefore, it remains an open topic to more fully understand the variation in reflectance properties of materials as observed in the real world.

This paper reports on work performed to merge the results of empirical reflectance property (spectral polarized bidirectional reflectance distribution function - spectral pBRDF) measurements of materials with detailed physical model based simulations with the goal of validating the modeling and allowing it to be used to extend the measurements to additional arbitrary conditions. The instrumentation used to collect the empirical data includes a commercial field spectroradiometer as well as an RIT-developed spectral polarized imaging goniometer. Characterization of the instruments and associated limitations is discussed. The modeling is performed using an adaptation of RIT's Digital Imaging and Remote Sensing Image Generation (DIRSIG) model to capture the radiative transfer occurring on rough surfaces with micron-scale features. Measurements and model results for several man-made materials observed under various conditions (e.g., dirty, wet) are

presented. The validated model results are used to extend the material reflectance characterization to more arbitrary conditions and insights provided into ways to capture the variability using statistical models.

7695-26, Session 7

Mapping and monitoring the beach and shallow water seafloor with lidar and hyperspectral systems

J. M. Wozencraft, U.S. Army Corps of Engineers (United States)

The U.S. Army Corps of Engineers (USACE) began developing lidar systems for coastal mapping applications in 1986, and fielded our first system in 1994. We have pursued evolution of the technology since that time. In 2005, we began collecting data with the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system, our first multi-sensor system. Our experience with CHARTS illustrates both the potential and the challenges of combining lidar and spectral data in the coastal environment. We have leveraged the CHARTS experience forward into the design of a new generation active/passive coastal mapping system: the Coastal Zone Mapping and Imaging Lidar (CZMIL). In this project, we began with the development of algorithms to produce a wide range of environmental products in a data fusion paradigm, and subsequently designed the software and hardware to achieve the desired results. We anticipate that CZMIL will achieve improved performance in shallow, turbid waters, will image the beach and seafloor simultaneously, and will produce environmental information describing the water column as well as the seafloor. The project is managed by Optech International, who are partnered with the University of Southern Mississippi. In the following papers, we will hear some aspects of the design of the algorithms, software, and hardware for CZMIL.

7695-27, Session 7

Overview of the coastal zone mapping and imaging lidar (CZMIL): a new multisensor airborne mapping system for the U.S. Army Corps of Engineers

G. H. Tuell, Optech International, Inc. (United States); K. Barbor, The Univ. of Southern Mississippi (United States); J. M. Wozencraft, U.S. Army Corps of Engineers (United States)

CZMIL is a new airborne mapping and imaging system designed to simultaneously produce high resolution 3D images of the beach and shallow water seafloor, and to achieve benthic classification and water column characterization. It is designed to have high performance in shallow, turbid waters. The Data Acquistion System (DAS) is composed of a new bathymetric lidar integrated with a commercial imaging spectrometer and digital metric camera. The Data Processing System (DPS) employs new algorithms and software designed to automatically produce environmental image products by combining data from the three sensors within a data fusion paradigm. CZMIL is specifically designed to meet the requirements of the USACE National Coastal Mapping Program, and is scheduled to enter field trials in the fall of 2010.

7695-28, Session 7

Prelude to CZMIL: seafloor imaging and classification results achieved with CHARTS and the rapid environmental assessment (REA) processor

J. Aitken, V. Ramnath, V. I. Feygels, A. Mathur, M. Kim, J. Y. Park, G. H. Tuell, Optech International, Inc. (United States)

Integration of a bathymetric lidar and imaging spectrometer in CHARTS presented the challenge of developing new algorithms and software for combining the two types of data. To support this development, we conducted several field campaigns to collect airborne and insitu data of the water column and seafloor. This work, sponsored by the Office of Naval Research (ONR) led to development of the Rapid Environmental Assessment (REA) Processor. REA can be used to produce seafloor reflectance images from both sensors, and classification maps of the seafloor. Ultimately, REA became the prototype software for CZMIL, and the CZMIL Data Processing System (DPS) has been produced as a continuous refinement of REA. Here, we describe the datasets collected and illustrate results achieved with the REA software.

7695-29, Session 7

A proposed field validation campaign for CZMIL

A. G. Cottin, S. A. Epps, K. Barbor, K. Martin, P. Heidingsfelder, The Univ. of Southern Mississippi (United States); J. Aitken, M. Kim, Optech International, Inc. (United States)

Upon the completion of the prototype CZMIL by Optech International, the University of Southern Mississippi will conduct a field validation campaign of the system in various environments to evaluate the accuracy of the sensors and the products derived from the data of those sensors, individually or combined. In addition to the IHO order 1 vertical and horizontal accuracy assessment of the CZMIL, the effectiveness of the DPS algorithms to map environmental parameters will be tested and estimated. This paper presents a preliminary plan to realize these accuracy assessments. To support these efforts, an array of in-situ sensors will be deployed on land and at sea, prior to and during the CZMIL surveys, to obtain a full environmental characterization of the survey site. This program will identify the material and the methodology for each selected environment to create a standard field survey procedure.

7695-30, Session 8

Conceptual design of the CZMIL data acquisition system (DAS): integrating a new bathymetric lidar with a commercial spectrometer and metric camera for coastal mapping applications

E. Fuchs, G. H. Tuell, Optech International, Inc. (United States)

The CZMIL Data Acquisition System (DAS) is composed of a lidar, spectrometer, camera, navigation system, and storage media running on a linux-based Gigabit Ethernet network. The lidar is a hybrid scanned-flash system employing a 10 KHz green laser and novel circular scanner, with a large aperture receiver (0.20m) having multiple channels. A PMT-based segmented detector is used on one channel to support simultaneous topographic and bathymetric data collection, and multiple fields-of-view are measured to support bathymetric measurements. The measured laser returns are digitized at 1 GHz to produce the waveforms required for ranging measurements, and unique data compression and storage techniques are used to address the large data volume.

7695-31, Session 8

Development of a novel green laser for the CZMIL system

J. W. Pierce, JP Innovations, LLC (United States); E. Fuchs, G. H. Tuell, Optech International, Inc. (United States)

The CZMIL system aims to expand Bathymetric lidar performance

in shallow water conditions, where high spatial and temporal data resolutions are required. This must be achieved without sacrificing performance in deep water. Very high frequency data collection (as high as 70KHz) utilizing a hybrid flash-point lidar approach is proposed, which places high demands on the transmitted laser beam, namely high pulse power with short pulse duration and very high fidelity beam characteristics. To meet these requirements, we have developed a compact, high-power, short pulse length, high repetition rate green laser with beam quality acceptable for use with the hybrid lidar approach employed in CZMIL. The short pulse length is achieved using a CW-pumped Q-switched oscillator, and the required power is achieved by using multiple amplifiers employing fiber coupled, CW end-pumped Nd:YVO4 crystals prior to doubling the 1064nm beam. The resulting output power in the green beam is nominally 30W at 10 kHz with a pulse length of < 2 ns FWHM.

7695-32, Session 8

Utilizing circular scanning in the CZMIL system

E. Fuchs, A. Mathur, Optech International, Inc. (United States)

In pursuit of increased reliability and improved signal levels, we employ a scanning approach that supports the high frequency acquisition requirements of the system while utilizing a large aperture receiver. A continuously rotating circular scanner was developed using direct inductance drives to rotate a Fresnel prism, acting as synchronized transmitter-receiver optical element with a fixed incident angle to the sea surface. Circular scanning introduces challenges in evaluating the system's coverage. By its nature, a circular scanning pattern introduces non-uniformity. Unlike galvo-based scanners roll and pitch compensation is practically impossible for a large mechanism, therefore careful planning is required to ensure continuous coverage under realistic operational conditions. Techniques to select optimal operation parameters are discussed as well as different ways to evaluate surface coverage.

7695-33, Session 8

Selection of COTS passive imagers for CZMIL

J. Aitken, J. Y. Park, A. Mathur, M. Kim, G. H. Tuell, Optech International, Inc. (United States)

The Coastal Zone Mapping and Imaging Lidar (CZMIL) is a multi-sensor airborne system with dedicated data fusion software producing 3D images and maps of environmental parameters describing the beach, seafloor and water column. To reduce overall program development risk, a commercial off-the-shelf (COTS) imaging spectrometer and digital metric camera are used. These imagers are installed on the same mounting plate as the lidar so as to share navigation data from a single inertial measurement unit (IMU). In this paper, we discuss the capabilities of the passive imagers as they relate to spatial and spectral requirements of the U.S. Army Corps of Engineers (USACE) mission, and illustrate the anticipated data coverage based on the expected deployment mode.

7695-34, Session 8

Proposed lidar receiver architecture for the CZMIL system

A. Payment, E. Fuchs, G. H. Tuell, V. I. Feygels, Optech International, Inc. (United States)

The receivers in the CZMIL system employ commercial photomultiplier tubes operated in the logarithmic mode coupled to 1 GHz custom digitizers. This architecture achieves sufficient dynamic range to support operating the system in both terrestrial and ocean environments. The multi-channel design of CZMIL requires the digitization of 9 channels of data. The resulting large data volume necessitated design of a novel data reduction and compression strategy.

7695-35, Session 8

Predicted lidar ranging accuracy for CZMIL

A. Mathur, V. Ramnath, E. Fuchs, J. Y. Park, G. H. Tuell, Optech International, Inc. (United States)

Range measurements in CZMIL are accomplished with signal processing techniques applied to green lidar waveforms. In the design phase of the project, we developed software to simulate waveforms for CZMIL, and have used these simulated waveforms to design ranging algorithms, and test their accuracies. Our results indicate the topographic ranging accuracy to hard targets should be on the order of 2cm. In this paper, we discuss the simulations, algorithms, and results.

7695-36, Session 9

Conceptual design of the CZMIL data processing system (DPS): algorithms and software for fusing lidar, hyperspectral data, and digital images

J. Y. Park, G. H. Tuell, Optech International, Inc. (United States)

The CZMIL DPS has been designed to automatically produce a number of novel environmental products through the fusion of lidar, spectrometer, and camera data in a single software package. These new products significantly transcend use of the system as a bathymeter, and support use of CZMIL as a complete coastal and benthic mapping tool. The DPS provides a spinning globe capability for accessing data files; automated generation of combined topographic and bathymetric point clouds; a fully-integrated manual editor and data analysis tool; automated generation of orthophoto mosaics; automated generation of reflectance data cubes from the imaging spectrometer; a coupled air-ocean spectral optimization model producing images of chlorophyll and CDOM concentrations; and a fusion based capability to produce images and classifications of the shallow water seafloor. Adopting a multitasking approach, we expect to achieve computation of the point clouds, DEMs, and reflectance images at a 1:1 processing to acquistion ratio.

7695-37, Session 9

Predicted bathymetric lidar performance of CZMIL

V. Ramnath, V. I. Feygels, Optech International, Inc. (United States); Y. I. Kopilevich, Saint-Petersburg State Univ. of Information Technologies, Mechanics and Optics (Russian Federation); J. Y. Park, G. H. Tuell, Optech International, Inc. (United States)

A significant challenge in the CZMIL program was to develop a topographic/bathymetric lidar delivering high spatial resolution 3D data in shallow, turbid waters, without sacrificing performance in deeper waters. To support analysis of the trade space inherent in the design process, we developed a waveform simulator capable of predicting CZMIL waveforms by varying parameters of the physical design and environmental properties of the seafloor and water column. Here, we describe the predicted performance of the proposed hardware and algorithms for generating seafloor point clouds in a number of simulated environments.

7695-38, Session 9

The CZMIL manual editor (CME): a new tool for analyzing bathymetric lidar waveforms and editing point clouds

G. Morris, The Univ. of Southern Mississippi (United States); J. Depner, Naval Oceanographic Office (United States); V. Ramnath, G. H. Tuell, Optech International, Inc. (United States); R. Hilderbrand, The Univ. of Southern Mississippi (United States)

The University of Southern Mississippi's Center of Higher Learning has developed a Waveform Viewer, Attribute Viewer, and a 3D Editor for use in the CZMIL Point Cloud Manual Editor (CME). The Waveform Viewer displays various channels of CZMIL waveforms within the 2D/3D editor interface of CME. This module provides the user an interactive tool set consisting of a cross sectioning mechanism for the intensity time-bin relationship, waveform file output, and zooming capabilities. The Attribute Viewer provides the data analyst with information to analyze various environmental and spatial parameters that might contribute to errors in the measured points. The 3D Editor offers the benefits of capturing depth outliers; an intuitive visual connectivity with the 2D editor; and the implementation of volumetric directional slice isolation of data outliers.

7695-39, Session 9

A constrained optimization technique for estimating environmental parameters from CZMIL hyperspectral and lidar data

M. Kim, J. Y. Park, G. H. Tuell, Optech International, Inc. (United States)

For the CZMIL DPS, we have developed a combined atmospheric-oceanographic spectral optimization solution decomposing measured airborne radiance data from the passive spectrometer into environmental parameters of interest. In this model, we hold depth measurements from the lidar as fixed constraints, thereby gaining a degree of freedom in the solution, and extending the solution into deeper waters than achieved with passive data alone. In this paper, we illustrate results of the data processing procedure and assess the accuracy of estimated iop parameters through comparison to in situ measurements.

7695-40, Session 9

Development of a suspended particulate matter (SPM) algorithm for CZMIL data

S. A. Epps, S. E. Lohrenz, K. Barbor, The Univ. of Southern Mississippi (United States); G. H. Tuell, Optech International, Inc. (United States)

Algorithms for estimation of the concentrations of suspended particulate matter (SPM) are being developed in order to fulfill USACE design requirements for CZMIL. The lidar sensor will be used to characterize the water column, including SPM concentrations. Because the lidar sensor uses an artificial light source (i.e., the laser), it is referred to as an active system. Additionally, CZMIL will make observations of the water column with a hyperspectral sensor, which records of the magnitude of water leaving radiance at multiple wavelengths. Since the hyperspectral sensor relies solely on ambient or natural light, it is considered a passive system.

This research includes the testing and validation of published models of SPM from passive spectral data produced by ship borne, airborne and satellite based sensors, and the development of a new active-passive data fusion algorithm. The new algorithm will combine observations from CZMIL's lidar and hyperspectral sensors. Data which are being collected in the northern Gulf of Mexico as part of an NSF-funded project will be applied to this research. These data come from ship-borne hyperspectral

radiometers, as well as in situ SPM and optical observations. The data will be used to validate the applicability published SPM algorithms to the project site. The active-passive fusion algorithm will be derived from the ship-borne hyperspectral observations in combination with simulated CZMIL signal data produced by Optech International.

7695-41, Session 9

Active-passive data fusion algorithms for seafloor imaging and classification from CZMIL data

J. Y. Park, V. Ramnath, V. I. Feygels, M. Kim, A. Mathur, J. Aitken, G. H. Tuell, Optech International, Inc. (United States)

CZMIL will simultaneously acquire lidar and passive spectral data. These data will be fused to produce enhanced seafloor reflectance images from each sensor, and combined at a higher level to achieve seafloor classification. In the DPS software, the lidar data will first be processed to solve for depth, attenuation, and reflectance. The depth measurements will then be used to constrain the spectral optimization of the passive spectral data, and the resulting water column estimates will be used recursively to improve the estimates of seafloor reflectance from the lidar. Finally, the resulting seafloor reflectance cube will be combined with texture metrics estimated from the seafloor topography to produce classifications of the seafloor.

7695-84, Poster Session

Analysis of spatial pattern and dynamic land-use change in the north Xinjiang economic zone of China

J. Qian, Q. Zhou, Hong Kong Baptist Univ. (Hong Kong, China); C. Xi, Xinjiang Institute of Ecology and Geography (China)

This study focuses on detecting the temporal and spatial expansion of built-up areas in the North Xinjiang Economic Zone of China during 1990-2006. Multitemporal satellite images including Landsat TM (1990, 1995), ETM (2000, 2002), CBERS (2005) and Beijing-1 (2006) are used to detect landuse/cover changes. Using Landsat TM imagery for urban and fringe land cover classification, a number of technical challenges exist for better outcome: (1) Conventional spectral classification methods do not perform well, particularly for differentiating built-up areas from bare soil and storey deserts. (2) The accuracy of automatic classification for retrieving urban landuse is not satisfactory. It is, therefore, necessary to develop a more effective and practical method to retrieve built-up area from its background. In this study we take an approach based on object oriented and rule-based methods to extract information of the built-up area in arid area. The classified images are then used for the analysis of temporal trajectory and spatial pattern of landuse change in the past 16 years. the methods of landscape ecology are applied to the temporal landuse change trajectory established using classified remote sensing images. The spatial pattern and spatial heterogeneity are analysed by employing and computing landscape metric variables including urban landscape diversity index, contagion index and fractal dimension. The results of this study will improve our understanding about urban expansion in the aridzone, where the development constraints in terms of natural and environmental resources greatly vary from those faced by the cities in the coastal region of China.

7695-85, Poster Session

A comparison study of dimension estimation algorithms

A. A. Schlamm, Rochester Institute of Technology (United States); R. G. Resmini, George Mason Univ. (United States); D. W. Messinger, W. F. Basener, Rochester Institute of Technology (United States)

The inherent dimension of hyperspectral data is commonly estimated for the purpose of dimension reduction. However, the dimension estimate may itself be a useful measure for extracting information about hyperspectral data, including scene content, complexity, and clutter. There are many ways to estimate the inherent dimension of data, each measuring the data in a different way. This paper compares a selection of dimension estimation metrics on a variety of data across platform, GSD, and scene content to determine if there is a relationship between different dimension estimates and the features each method is measuring within complex data.

7695-87, Poster Session

Spectral face recognition using orthogonal subspace bases

A. Wimberly, Oberlin College (United States); S. A. Robila, Montclair State Univ. (United States); T. Peplau, St. Lawrence Univ. (United States)

Accurate individual identification is an essential part of any authentication protocol. Often, such identification is done using biometrics. Among biometrics, face recognition provides an unobtrusive and if needed discrete method of classifying individuals, a task that has become increasingly important in many fields swamped by deluge of data available (but lack of human analysts) such as surveillance, law enforcement, and access control. Spectral imaging, i.e. images collected over hundreds of narrow contiguous light spectrum intervals constitute a natural choice for expanding face recognition image fusion, especially since it may provide information beyond the normal visible range, thus exceeding the normal human sensing. While face recognition from grayscale or color images has seen a considerable research effort, little was done to investigate the use of spectral imaging for this problem. Previous studies have focused on various experiments aimed at analyzing the subjects' spectral separability from other data.

Our work is geared at designing an efficient method for facial recognition by using hyperspectral imaging and orthogonal subspaces. Projecting the data into orthogonal subspaces provides the unique advantage of compactness and reduction of data redundancy. In our case we focus on two approaches: Principal Component Analysis (PCA), and Orthognal Subspace Projection (OSP). Our work can be separated in three main stages. In the first we have designed an experimental setup that allowed us to create a hyperspectral image database of 17 subjects each with four different facial expressions and viewing angles. Second, we investigated approaches to employ spectral information for the generation of fused grayscale images. Here we have looked at both fusion through averaging as well as orthogonal projections. Third, we designed and tested a recognition system based on the methods described above (PCA and OSP). Our results show that spectral fusion leads to improvement of recognition accuracy when compared to regular imaging. In a fourth complimentary direction we also looked at the reliability of the recognition system by investigating facial expression's impact on face recognition.

The work expands on previous band extraction results and has the distinct advantage of being one of the first that combines spatial information (i.e. face characteristics) with spectral information. In addition, the techniques are general enough to accommodate differences in skin spectra.

7695-88, Poster Session

Image Sharpening Toolkit (ISTK)

D. Pulido, SAIC (United States)

There has been significant research on specific image sharpening algorithms, but there has been less work incorporating them into a robust and validated tool. We present the Image Sharpening Toolkit (ISTK), a collection of four validated algorithms (3 novel, 1 literature based) that provide error propagation as well as radiometric, spectral, and spatial fidelity. One of the algorithms sharpens a single-band image (e.g. thermal image) with another single-band image (e.g. visible panchromatic image) by exploiting the HSV color model to produce a three-band color image. The other three algorithms sharpen a multispectral image with a single panchromatic image. One of these algorithms can also sharpen a hyperspectral image with a multispectral image. These techniques exploit the physics of a sensor, including knowledge of its Tasseled Cap coefficients and Spectral Response Function. The suite of algorithms in ISTK were chosen to maintain radiometric, spectral, and spatial accuracy to varying degrees, dependent of the user's need. We demonstrate the tool's performance on QuickBird and IKONOS imagery.

7695-89, Poster Session

Unmixing and anomaly detection in hyperspectral data due to cluster variation and local information

J. M. Maerker, W. Middelmann, FGAN-FOM (Germany); J. Huber, Univ. Basel (Switzerland)

Several algorithms for end-member extraction and unmixing have been reported in the literature. End-member extraction algorithms search for pure materials that constitute the significant structure of the environment. For abundance estimation in hyperspectral imagery, various physically motivated least squares methods are considered.

In real hyper spectral data, the signatures of each pure material vary with physical texture and perspective. In this work, a clustering of the data is performed and normal distributions - instead of constant signatures - are used to represent the end-members.

This kind of end-member representation allows determining class membership by means of unmixing. Furthermore a parameter optimization is performed. Using only end-members in a spatial window around each pixel better fits a physical model. This new approach is called 'Cluster Mixing' (CM). As a result of the local approach, the residual of the reconstruction indicates the magnitude of anomalies.

The efficiency of the cluster mixing is shown by a comparison with other algorithms. CM's usefulness as an anomaly detector is demonstrated.

7695-90, Poster Session

Evaluation of different structural models for target detection in hyperspectral imagery

C. Peña-Ortega, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Target detection is an essential component for defense, security and medical applications of hyperspectral imagery. Structured and unstructured models are used to model variability of spectral signatures for the design of information extraction algorithms. In structured models, all spectral signatures for the background or target classes are contained within some subset of an n-dimensional Euclidean space, where n is the number of bands. In linear approaches, the spectral signatures are assumed to be generated by the linear combination of basis vectors. The nature of the basis vectors and of the allowable linear combinations, define different structural models. In one approach, the spectral variability of the signatures is assumed to be contained in a vector subspace spanned by the target or background signatures. In other approaches, the signatures are assumed to be contained in a polyhedral cone or in the convex hull for the target or background classes. In this paper, we investigate the use of these models to model background in a detection application and study the performance of target and anomaly detection algorithms based on these models. The comparison assesses the relative performance of the algorithms using ROC. Furthermore, we study the estimation of the minimal number of vectors needed to generate the models by using the linear rank and the positive rank. Results show that structured models based on polyhedral cones and convex hulls that take into consideration the physical properties of the data outperform subspace methods for target detection. Experimental results using HYDICE imagery are presented.

7695-91, Poster Session

Using support vector data description for anomaly detection in hyperspectral images

S. Khazai, S. Homayouni, A. Safari, Univ. of Tehran (Iran, Islamic Republic of)

Recently, anomaly detection has become, particularly, an interesting application of hyperspectral remote sensing. The aim here is to identify the pixels that have the spectral signatures, significantly different from the neighboring background. Anomaly detection does not require a priori knowledge of the targets and atmospheric/radiometric corrections. Consequently, it can be considered as the first step of Automatic Target Recognition (ATR) analysis. The results will be detected pixels of interest, which may contain potential targets.

In this research, Support Vector Data Description (SVDD), which is a non-parametric statistical approach, has used for anomaly detection. As kernel function, a heuristic local Radial Basis Function (RBF) is employed. Then in the next stage, clustering technique is applied to separate and to classify the anomalous targets. This strategy could help to reduce the search space of targets in ATR analysis. In addition, the Principal Component Transformation (PCT) is investigated for hyperspectral dimensional reduction to assess the ability of anomalies detection.

The approach was applied to the Target Detection Blind Test data. This dataset includes the HYMAP radiance image data of Cook city in Montana. The image covers a semi urban area with some small fabric panels and vehicles, as potential targets, were imaged at whole and sub pixel scale. The results are evaluated and compared with kernel-RX and Banerjee's SVDD approaches, in term of detection accuracy and computation performance.

7695-92, Poster Session

Accuracy assessment of land cover dynamic in hill land on integration of DEM data and TM image

Y. Li, X. Wang, Nanjing Normal Univ. (China)

To accurately assess the area of land cover in hill land, we integrated DEM data and remote sensing image in Lihe River Valley. Firstly, the DEM data was combined into decision tree to increase the accuracy of land cover classification. Secondly, a slope corrected model was built to transfer the projected area to surface area by DEM data. At last, the area of different land cover was calculated and the dynamic of land cover in Lihe River Valley were analyzed from 1998 to 2003. The results show that: the area of forestland increased more than 10% by the slope corrected model, that indicates the area correcting is very important for hill land; the accuracy of classification especially for forestland and garden plot is enhanced by integrating of DEM data. It can be greater than 85%. The indexes of land use extent were 266.2 in 1998, 273.1 in 2001, and 276.7 in 2003. The change rates of land use extent were 2.59 during 1998 to 2001 and 1.34 during 2001 to 2003.

7695-93, Poster Session

Subpixel target detection and enhancement in hyperspectral images

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Hyperspectral data due to its higher information content afforded by higher spectral resolution is increasingly being used for various remote sensing applications including information extraction at subpixel level. There is however usually a lack of matching fine spatial resolution data particularly for target detection applications. Thus, there always exists a tradeoff between the spectral and spatial resolutions due to considerations of type of application, its cost and other associated analytical and computational complexities. Typically whenever an object, either manmade, natural or any ground cover class (called target, endmembers, components or class) gets spectrally resolved but not spatially, mixed pixels in the image result. Thus, numerous manmade and/or natural disparate substances may occur inside such mixed pixels giving rise to mixed pixel classification or subpixel target detection problems. Various spectral unmixing models such as Linear Mixture Modeling (LMM) are in vogue to recover components of a mixed pixel. Spectral unmixing outputs both the endmember spectrum and their corresponding abundance fractions inside the pixel. It, however, does not provide spatial distribution of these abundance fractions within a pixel. This limits the applicability of hyperspectral data for subpixel target detection. In this paper, a new inverse Euclidean distance based super-resolution mapping method has been presented that achieves subpixel target detection in hyperspectral images by adjusting spatial distribution of abundance fraction within a pixel. Results obtained at different resolutions indicate that super-resolution mapping may effectively aid subpixel target detection.

7695-94, Poster Session

Orthogonal subspace projection approach to finding signal sources in hyperspectral imagery

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Automatic Target Generation Process (ATGP) was previously developed for automatic target recognition. Its usefulness has been demonstrated in many applications. This paper presents a new application of the ATGP in determining the number of signal sources as well as finding these signal sources in hyperspectral imagery. The idea is to categorize signal sources into target and background classes in terms of their inter-sample spectral correlation (ISSC). Two separate designed algorithms, Unsupervised Target Sample Generation (UTSG) and Unsupervised Background Sample Generation (UBSG) are designed for this purpose where the former is designed to capture signal sources whose ISSC is characterized by high order statistics while the latter extracts signal sources whose ISSC is characterized by 2nd order statistics. The UTSG implements the ATGP in the sphered hyperspectral data to determine and find target signal sources at the same time. These target samples form a desired target class. It is followed by the UBSG which operates the ATGP on a space orthogonal to the subspace generated by the target class to determine and find background signal sources which form the desired background class. Two data sets, synthetic image data and real image scenes are used for experiments. Experimental results demonstrate that the UTSG and UBSG are effective in extracting signal sources in various applications

7695-42, Session 10

Instrument lineshape modeling for ultraspectral imagery measurements of industrial smokestack emissions

K. C. Gross, Air Force Institute of Technology (United States); P. Tremblay, Univ. Laval (United States); V. Farley, Telops (Canada); G. P. Perram, Air Force Institute of Technology (United States)

The Telops Hyper-Cam midwave (InSb 1.5-5.5 μm) imaging Fourier-transform spectrometer observed the plume from a coal-burning power plant smokestack. From a distance of 600 meters, the plume was captured on a 128x64 sub-window of the focal-plane array with each pixel imaging a 21x21 cm2 region. Asymmetric interferograms were collected with the long side corresponding to a maximum optical path difference of 2.4 cm which is an unapodized spectral resolution of 0.25 cm-1. Strong line emissions from CO, CO_2, SO_2, and HCl were observed across 1800-3000 cm-1, and emission features from H_2O and NO were identified after accounting for atmospheric attenuation. A simplified radiative transfer model was used to estimate plume temperature and gas concentrations, and good agreement with in situ measurements was obtained. However, model fits to the full-resolution spectrum suggested the need to account for a non-ideal instrument lineshape function. In this work, we develop a non-ideal instrument lineshape function using the spectrally-isolated HCl lines to improve quantitative modeling of the plume spectra.

7695-43, Session 10

An atmospheric perturbation model for VNIR/SWIR hyperspectral processing

G. E. Healey, Univ. of California, Irvine (United States)

to be generated

7695-44, Session 10

Vision inspired spatial engine (VISE): automated object registration for multisource fusion

D. R. Lewis, SAIC (United States); D. Edwards, National Geospatial-Intelligence Agency (United States); D. Pulido, J. Hufnagel, M. Kim, SAIC (United States)

Automated registration has been pursued for decades within academia, government, and commercial sectors as a fundamental enabling technology to support improved positioning, automated change detection, target recognition, and multi-source fusion. The focus of previous and current research has largely been on automated image-to-image registration tools. Comparatively little attention has been paid to automated registration of non-raster data (e.g., vector) stored within Geographical Information Systems (GIS) or other types of databases.

The Vision Inspired Spatial Engine (VISE) is an innovative approach to automated registration. Rather than focusing on automated registration of a specific data source such as imagery, VISE uses a novel object-matching paradigm which is independent of data source. VISE closely emulates key characteristics of both human perception and problem solving. The technology has been applied to a number of challenging problems using real world data from existing databases. In its pattern match role, VISE assesses the fuzzy spatial similarity between two or more object patterns that can be of arbitrary/differing shape or size by use of a top-down multiple resolution approach that simultaneously optimizes both edge and area match between vector-represented spatial features. As a by-product of the VISE pattern-matching process, object-to-image registration, change detection, and automated validation between different data sources are possible.

This presentation demonstrates the VISE technology applied toward the automated registration and object-level correlation of Hyperspectral (HSI), LIDAR and Electro-Optical (EO) Imagery and derived objects, and other GIS data sources.

7695-45, Session 10

Quantitative image restoration

I. Gladkova, M. D. Grossberg, F. Shahriar, The City College of New York (United States)

A common problem in satellite imagery is striping and scan line dropout. While transmission errors are sometimes the cause of this problem, a more frequent source is damage to individual detectors, or to the electronics that records the response of the detectors. Detectors are highly sensitive and precise elements, and despite extraordinary precautions and planning, damage is an unavoidable risk. Launch, deployment into the harsh environment of space, particle bombardment, radiation, and space dust can result in detector damage at any point of an imager's life cycle. There are many examples of imagers which suffer from periodic line drop. Classical examples include Landsat 4 and 5. More recent examples include MODIS on Aqua, which has 60% of broken detectors in 1.6 micron band. To use standard image processing operations and off the shelf software, the missing data must be first estimated in some principled way. End users may have little or no knowledge of how to do that. It is important to note that many end users will often work with partial data, selected bands or regions of interest. This both magnifies the impact of missing data and makes it harder to accurately compute a principled estimate. Unlike currently used spatial estimation methods, the statistical regression we propose to use for restoration exploits the redundant information presents in other spectral band of the imager. The estimator we propose, will use values in a spectral/spatial neighborhood of the pixel to be estimated, and propose a value based on training data from the uncorrupted pixels. Due to the non-parametric nature of the estimator, we avoid the blurring inherent spatial interpolation, which have implicit smoothness priors. We will present a family of algorithms which will allow a tradeoff of speed for accuracy making the algorithm more widely applicable.

7695-46, Session 10

Dimensionality reduction, classification, and spectral mixture analysis using nonnegative underapproximation

N. Gillis, Univ. Catholique de Louvain (Belgium); R. J. Plemmons, Wake Forest Univ. (United States)

A crucial aspect of hyperspectral image analysis is the identification of the materials present in the object or scene being imaged. In this framework, dimensionality reduction techniques such as PCA are widely used to extract pertinent information and to help finding the underlying structure of the data. In this context, it is often preferable to take the nonnegativity constraint of the images into account in order to enhance interpretability of the extracted factors: this is the so-called Nonnegative Matrix Factorization (NMF) technique which has been successfully used in many applications, e.g., text mining, air emission control, collaborative filtering, clustering, etc. NMF is particularly well-suited to achieve a parts-based and sparse representation of the data, enhancing interpretability of the decomposition. However, NMF is a nonlinear optimization problem with many local minimizers and the solution is in general non-unique; moreover, one needs to recompute a solution from scratch when the rank of the approximation is modified.

In this study, we present a new variant of NMF called Nonnegative Matrix Underapproximation (NMU): it is based on the introduction of underapproximation constraints which enables one to extract features in a recursive way, like PCA, but preserving nonnegativity. Moreover, we explain why these additional constraints make NMU particularly well-suited to achieve a parts-based and sparse representation of

the data. We experimentally show the efficiency of this new strategy on hyperspectral images associated with space object material identification, and on HYDICE and related remote sensing images.

7695-47, Session 10

Parameters selection of morphological scale-space decomposition for hyperspectral images using tensor modeling

S. Velasco-Forero, J. Angulo, Ecole Nationale Supérieure des Mines de Paris (France)

Dimensionality reduction (DR) is a major issue to improve the efficiency of the classifiers in hyperspectral images (HSI). Recently, DR using tensor structures in morphological scale-space decomposition (MSSD) based on morphological leveling for HSI has been investigated in order to incorporate spatial information in DR task. In this paper, we present results of a comprehensive investigation of two issues underlying DR in MSSD. Firstly, information contained in the tensor structure produced by MSSD is reduced using high-order singular value decomposition (HOSVD). Therefore, the objective function in HOSVD is nonconvex implicating that in some cases a large number of local solutions can be found. This is an essential problem, because if the solution is not unique, the results are not repeatable. For all experiments, HOSVD always reach a unique global solution in the parameter region suitable to practical applications. Secondly, scale parameters in MSSD are presented in relation to connected components size. Additionally, classification results are evaluated for various real HSI.

7695-48, Session 11

Improved feature extraction from high-resolution remotely sensed imagery using object geometry

H. G. Momm, G. Easson, B. Gunter, Univ. of Mississippi (United States)

Information extraction from high spatial resolution imagery is sometimes hampered by the limited number of spectral channels available from these systems. Standard supervised classification algorithms found in commercial software packages may misclassify different features with similar spectral characteristics; leading to a high occurrence of false positives. An additional step in the information extraction process was developed incorporating the concept of object geometry. Objects are defined as a contiguous group of pixels identified as belonging to a single class in the spectral classification step. Using the results from the spectral classification, a supervised approach is developed using genetic programming as an optimization algorithm to select and mathematically combine feature-specific shape descriptors, from a larger set of shape descriptors, to form a new classifier. This investigation focused on extraction of residential housing from QuickBird and IKONOS imagery of the Gulf Coast before and immediately after hurricane Katrina. Use of genetic programming significantly reduced false positives caused mainly by asphalt pavement and isolated roofing shingles scattered throughout the image. Comparisons of findings with reference data sets yielded kappa coefficient of agreement values ranging from 0.8 to 0.9. The result of this research is a robust system that can be used to rapidly assess damage to residential housing caused by a hurricane.

7695-49, Session 11

Study on the use of complexity measures for estimation of correct classification percentage in hyperspectral imagery

S. D. Hunt, O. Martinez, Univ. de Puerto Rico Mayagüez (United

States)

This study presents image complexity measures applied to hyperspectral images and their relation to the percentage of correct classification (PCC). Specifically, it studies the relationship between these metrics and the PCC for Maximum Likelihood and Angle Detection classifiers. First, many complexity measures were studied to determine if there was a relation between the measure and the PCC. Results showed a correlation of above 0.7 between complexity measures based on entropy and uncertainty and the PCC of the classifiers mentioned above. Once the relation was established, PCC estimators based on the metrics using simple and multiple regression models were designed. This design was performed using using data from both synthetic and real images. The real images were from two hyperspectral sensors, the space based AISA and and a portable SOC 700 hyperspectral sensor, and include scenes from the Enrique Reef in La Parguera Puerto Rico. The models were then tested with real data. Results show that confidence intervals on the PCC can be reliably obtained for real images.

7695-50, Session 11

Spherical harmonics as a shape descriptor for hyperspectral image classification

F. Nina-Paravecino, V. B. Manian, Univ. de Puerto Rico Mayagüez (United States)

Hyperspectral images have traditionally been analyzed by pixel based methods. Invariant methods that consider surface and shape geometry have not been used with these images. However, there is a need for such methods due to the spectral and spatial variability present in these images. In this paper, we develop a method for classifying these images invariant to translation and rotation. The method is based on developing shape descriptors using spherical harmonics. These orthogonal functions have been widely used as a powerful tool for 3 D shape recognition and are better suited for hyperspectral images due to its inherent dimensionality. A spherical function defined on the surface of a shape extracts rotation invariant features. In this case, the hyperspectral image is converted to spherical coordinates, decomposed as a sum of its harmonics and then converted to cartesian coordinates. The descriptors are computed on a subset of bands. A classifier is trained with spherical harmonic descriptors computed from training samples. Distance metrics and support vector machines are considered for classification. The method is tested with synthetic hyperspectral camera images and HYDICE sensor images. The results show that the descriptors are effective in discriminating objects under invariant conditions such as due to rotation, translation and illumination. Receiver operating characteristic curves show the detection capability of these descriptors.

7695-51, Session 11

Semi-supervised hyperspectral image segmentation using regionalized stochastic watershed

J. Angulo, S. Velasco-Forero, Ecole Nationale Supérieure des Mines de Paris (France)

Stochastic watershed is a robust method to estimate the probability density function (pdf) of contours of a multi-variate image using MonteCarlo simulations of watersheds from random markers. The aim of this paper is to propose a stochastic watershed-based algorithm for segmenting hyperspectral images using a semi-supervised approach. Starting from a training dataset consisting in a selection of representative pixel vectors of each spectral class of the image, the algorithm calculate for each class a membership probability map (mpm). Then, the mpm of class k is considered as a regionalized density function which is used to simulate the random markers used in the MonteCarlo estimation of the pdf of contours of the corresponding class k. This pdf favours the spatial regions of the image spectrally close to the class k. After applying the same technique to each class, a series of pdf are obtained

for a single image. Finally, the pdf's can be segmented hierarchically either separately for each class or after combination, as a single pdf function. In the results, besides the generic spatial-spectral segmentation of hyperspectral images, the interest of the approach is also illustrated for target segmentation.

7695-52, Session 12

Hyperspectral change detection via optimization

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Within the hyperspectral community, change detection is a continued area of interest. Specifically, change detection refers to the problem of comparing hyperspectral scenes collected on different occasions and identifying interesting changes that have occurred. These interesting changes often take the form of objects being inserted or removed from the scene between collections. Complicating the problem of change detection is the presence of shadow, illumination, and atmospheric differences between the scenes which often produce the appearance of change when indeed the material of the underlying pixel itself has not changed. The majority of change detection algorithms employ linear predictors to effectively normalize or remove the illumination and atmospheric differences between the scenes. Upon applying the predictor, a subtraction and detection step are then applied on a pixel by pixel basis to identify changes. These approaches typically suffer due to non-stationarity of statistics within the scene and the difficulty associated with shadow differences. The approach suggested here views the problem more from a data fitting perspective. Using a physical model for the sensed illumination, an optimization technique is developed under the assumption that the material reflectance associated with each pixel has not changed. The physical model incorporates terms to account for both direct and diffuse shadow fractions. A nonlinear optimization technique is applied to determine the unknown parameters of the model to produce a best fit for the associated time-1 and time-2 measurements. After estimating the parameters, the fit error can be used as an indicator of change. In order to apply an optimization approach, the illumination and atmospheric components of the model are limited to a lower dimensional subspace which is derived using MODTRAN atmospheric modeling.

7695-53, Session 12

Total least squares for anomalous change detection

J. Theiler, A. M. Matsekh, Los Alamos National Lab. (United States)

The problem of anomalous change detection arises when two (or possibly more) images are taken of the same scene, but at different times. The aim is to discount the "pervasive differences" that occur thoughout the imagery, due to the inevitably different conditions under which the images were taken (caused, for instance, by differences in illumination, atmospheric conditions, sensor calibration, or misregistration), and to focus instead on the "anomalous changes" that actually take place in the scene. In general, anomalous change detection algorithms attempt to model these normal or pervasive differences, based on data taken directly from the imagery, and then identify as anomalous those pixels for which the model does not hold. This paper will examine the situation in which this model is linear, and compare detectors that are are based on fitting the data using ordinary least squares versus total least squares. The total least squares formalism, when applied to whitened data, turns out to be equivalent to "optimized covariance equalization," which in turn is equivalent to "multivariate alteration detection," both of which can be expressed in terms of canonical correlation analysis. In addition to identifying the mathematical links between these various algorithms, the formalism also provides a principled way to do dimension reduction. The performance is evaluated using both real and a hybrid of real and simulated data, and it is found that this dimension reduction can lead to substantially improved performance.

7695-54, Session 12

Iterative convex hull volume estimation in hyperspectral imagery for change detection

A. K. Ziemann, D. W. Messinger, W. F. Basener, Rochester Institute of Technology (United States)

This paper will present an algorithm focused specifically on change detection in hyperspectral imagery. Historically in change detection, statistical methods have been used. However, as the spatial resolution of spectral images improves, the data no longer maintain a Gaussian distribution, and some assumptions about the data are not met. Consequently, algorithms based upon those statistical assumptions can produce results that are less than satisfactory. This algorithm takes a geometrical approach and uses the linear mixture model which approximates the convex hull enclosing the data through identification of the simplex vertices called endmembers. The method takes as input two registered images and tiles them. Next, the algorithm iterates through the tiles and for each set of pixels it identifies the number of corners (as vectors) that define the simplex of the set of data. It then iterates through the increasing dimensionality, or number of endmembers, while each time calculating the volume of the simplex defined by those endmembers. When the volume is calculated in a dimension that is higher than that of the inherent dimensionality of the data, the volume will theoretically drop to zero. The volume of the simplex will fluctuate when a new material is introduced to the dataset, indicating a change between the two image tiles. The values of these metrics will be compared using hyperspectral imagery collected over experimental setups with known changes between flights. Results from these tests will be presented along with a path forward for future research.

7695-55, Session 12

A novel method for change detection in spectral imagery

A. A. Schlamm, D. W. Messinger, W. F. Basener, Rochester Institute of Technology (United States)

A new method for change detection on a large area scene based on the point density of the pixel distribution in the hyperspace is presented. This method is derived from the point density approach to hyperspectral analysis, originally developed for material discrimination based on inherent dimension estimation. In this method, two registered large area scenes are tiled for individual scoring and comparison. The point density tail length is estimated for each tile in both scenes. The difference between this length for corresponding tiles indicates whether change has likely occurred in a tile and how significant the change is. The method does not identify changes in individual pixels, but uses a tiling approach to identify changes in small sub-regions of the image. Preliminary results of this methodology are presented for multiple images and changing scene phenomenology.

7695-56, Session 12

Variability analysis and change characterization of HSI data for urban mapping

F. A. Kruse, R. C. Olsen, Naval Postgraduate School (United States)

Urban areas are highly variable in remote sensing data, thus it can be difficult to detect changes over time caused by development or by movement of specific targets. This research evaluates repeat flights of high-spatial-resolution HSI data to identify and characterize sources and the nature of spectral variability in urban environments. Data for two dates were geocorrected and co-registered, then cropped to common spatial coverage. A MODTRAN atmospheric model was used to

independently correct for atmospheric effects in each dataset. Spectra for individual pixels and for ROIs were extracted from the data and visual and statistical comparisons were made between spectra to assess the effects of collection parameters and atmospheric corrections. Spectral endmembers were determined for each flightline and compared across flightlines. The distribution of endmembers was mapped using spectral matching methods and variability envelopes were defined for specific endmembers. The use of endmembers from one dataset to characterize the second dataset was also evaluated. The reflectance corrections were then refined by extracting spectral signatures in overlapping areas and applying an empirical line correction to enable direct comparison of differences in fine spectral detail for specific endmembers between flightlines. This approach allowed determination of relatively spectrally invariant areas versus areas with significant spectral change. A composite site "background" image was constructed, utilizing the invariant pixels to improve SNR and decrease spectral clutter. The combined datasets were used to develop thematic layers and evaluate changes in spectral character versus changes due to urban development and target replacement.

7695-57, Session 13

L1-endmembers: a robust endmember detection and spectral unmixing algorithm

A. Zare, P. D. Gader, Univ. of Florida (United States)

An hyperspectral endmember detection and spectral unmixing algorithm based on an L1-Norm factorization of the input hyperspectral data is presented. This algorithm, L1-Endmembers, simultaneously and autonomously estimates endmembers, proportion values, and the number of endmembers needed for an input hyperspectral image. An L1-Norm factorization is approximated using the Huber M-estimator. The Huber M-estimator provides an endmember detection method that is robust to outliers and noise in the data set.

L1-Endmembers determines the endmembers, abundances and the number of endmembers by minimizing an objective function containing three terms. The first term of the objective function uses the Huber M-estimator to minimize the error between the input data points and their reconstruction using endmembers and abundance values, ||X-EP'||. The second term, a sum of squared distances between all the estimated endmembers, promotes endmembers that tightly enclose the hyperspectral data. The final term is used to determine the number of endmembers by placing a sparsity-promoting Laplacian prior on the abundances associated with each endmembers. This sparsity-promoting prior drives the proportions of unneeded endmembers to zero allowing the removal of these endmembers without any effect on the error term in the objective. The L1-Endmembers algorithm iteratively minimizes the objective function by holding either the endmember or abundance values constant while solving for the other.

Results showing that the algorithm is stable and accurate with increasing levels of noise and outliers are presented.

7695-58, Session 13

Endmember extraction in hyperspectral images using l-1 minimization and linear complementary programming

D. T. Nguyen, T. D. Tran, The Johns Hopkins Univ. (United States); C. Kwan, B. Ayhan, Signal Processing, Inc. (United States)

Each pixel in Hyperspectral Images (HI) may contain information of more than one material. In addition, results from different un-mixing methods show HI have sparse representations, which means among the abundances, only a few are dominant, the rest are near or equal zero. In other words, each spectral pixel, either a target or background material, can be approximated by a linear combination of a few signatures. The sparse nature of data gives rise to introducing the sparsity regularized

term into objective functions to promote sparse solutions as well as to eliminate the susceptibility to noise of methods which use only Least Square measure.

Endmember extraction in HI is a critical step for target detection and abundance estimation. In this paper, we propose a new approach, which takes advantage of the sparsity, to endmember extraction. Sparsity is measured by the l_0 norm of the abundance vector. It is also well known that l_1 norm well resembles l_0 in boosting sparsity while keeping the optimization problem convex and tractable. Adding the l-1 term, we result in a constrained quadratic programming then solve it using the Linear Complementary Programming (LCP). Unlike existing methods which require expensive computations at each iteration, LCP only requires pivoting steps, which are extremely simple and efficient for un-mixing problem. Preliminary experiments of the proposed method showed competitive results as compared to LS-based methods like Non-negativity Constrained Least Square (NCLS) and Fully Constrained Least Square (FCLS). Furthermore, combination of our unsupervised decomposition with anomaly detection makes a decent target detection algorithm compared to state-of-the-art methods which require prior information of target/ background signatures.

7695-59, Session 13

Endmember finding and spectral unmixing using least-angle regression

A. R. Boisvert, A. D. Stocker, P. V. Villeneuve, Space Computer Corp. (United States)

The analysis of hyperspectral data often involves taking a hyperspectral image scene and unmixing it. This is a two-step process. The first step is to identify "pure" spectra known as endmembers from the scene, and the second step is to represent each pixel in the scene as a linear combination of the endmembers. Ideally, this linear combination would satisfy the following constraints: non-negativity, so that the coefficients of the endmembers are always non-negative, and sum-to-one, so that the sum of the coefficients equals 1. However, satisfying these constraints has until recently required methods such as non-linear programming, which is too slow for reasonable applications. We propose a new endmember finder and spectral unmixing algorithm based on the LARS/LASSO method for linear regression and model building. The endmember finder proceeds iteratively, at each step choosing a new endmember by finding the in-scene pixel which is least well-explained by the current endmembers. The unmixing algorithm uses the LASSO regression in a straightforward manner to describe a pixel as a constrained sum of endmembers, enforcing positivity and forcing the sum of the coefficients to be no greater than one. This algorithm successfully unmixes simulated data, and shows promising results on real data as well.

7695-60, Session 13

Learning hyperspectral endmembers and sparse abundances

J. B. Greer, National Geospatial-Intelligence Agency (United States)

The linear mixture model for hyperspectral images assumes that all the image spectra lie on a high-dimensional simplex with corners called endmembers. Given the set of endmembers, one typically calculates fractional abundances for each pixel using constrained least squares. Such methods likely reconstruct the spectra as combinations of most, if not all, the endmembers. We instead assume that pixels are combinations of only a few of the endmembers, yielding sparse abundance vectors (few nonzero entries). We introduce a new method, similar to matching pursuit from the signal processing literature, to calculate such sparse abundances. The user inputs an allowable error, and the algorithm computes the smallest collection of endmembers yielding a representation lying within this error range. We apply the method to artificial spectral data with added noise, and compare our

sparse representations with those derived from constrained least squares. We make similar comparisons on actual hyperspectral data.

We also combine our sparse demixing algorithm with dictionary learning methods to automatically calculate endmembers for a provided set of spectra. This is a fast iterative method with a number of operations that grows linearly with the size of the training set. We apply our method to hyperspectral images including an AVIRIS collect over Cuprite, NV, for which we compare our results to the USGS spectral library. We compare our results with N-FINDR, a standard algorithm used for calculating endmembers.

7695-61, Session 13

Fast algorithm for searching endmember set per pixel

Q. Du, Mississippi State Univ. (United States)

Linear mixture model (LMM) is widely used in remote sensing image analysis. It is particularly useful for hyperspectral image analysis due to the fact that its high dimensionality permits the retrieval of endmember abundances even when the number of endmembers is large. In the original LMM, it is assumed that each pixel is a linear combination of all the endmember signatures. For an image scene covering a large geospatial area, the number of endmembers is large and only a small subset of these endmembers may actually participate in the composition of a specific pixel. If all the endmembers are used in the linear unmixing process, the result may contain additional estimation error. In our research we do not prefer the fully constrained linear unmixing which forces the sum-to-one and non-negativity constraints to be satisfied, because an endmember set should be able to automatically satisfy these two constraints if it appropriately represents the mixing process. We have developed approaches that can automatically search for an endmember subset for each pixel in a hyperspectral image, which is different from pixel to pixel. Due to high computational complexity, in this paper, we will develop a fast searching algorithm by considering the neighborhood relationship among pixels. We will show that the resulting endmember sets can reduce pixel reconstruction error and improve the quality of estimated abundances (i.e., all the pixels have nonnegative abundances and most of pixels have sum-to-one abundances).

7695-62, Session 13

Fast algorithms to implement N-FINDR for hyperspectral endmember extraction

W. Xiong, C. Chang, K. Kalpakis, Univ. of Maryland, Baltimore County (United States)

N-FINDR suffers from several issues in its practical implementation. One is the search region which is usually the entire data space. Another related issue is its excessive computation. A third issue is the use of random initial conditions which causes inconsistency in final results that can not be reproducible. This paper develops several fast computational algorithms for the N-FINDR. One is to narrow down the search region for the N-FINDR to a feasible range where the well-known pixel purity index (PPI) is used for this purpose. In addition, in order to further reduce computational complexity two sequential N-FINDR algorithms are developed which implement the N-FINDR by finding one endmember after another in sequence so that the information provided by previously found endmembers can be used to reduce computational complexity. The conducted experiments demonstrate that while the proposed fast algorithms can greatly reduce computational complexity, their performance remains as good as the N-FINDR is and is not compromised by reduction of search region by PPI.

7695-63, Session 13

Understanding the impact of spatial resolution in unmixing of hyperspectral images

A. Santos-Garcia, M. Velez-Reyes, Univ. de Puerto Rico Mayagüez (United States)

Proposed and existing hyperspectral remote sensors, provide information about the scene of interest at resolutions ranging from 20m to 1 km in terrestrial and space applications. Understanding the quality of the information extracted with image exploitation algorithms and how does it relate to actual spectra on the ground are important problems when we look into algorithms that perform unmixing of hyperspectral images to perform subpixel analysis. In this paper, we investigate how spatial resolution limits the information that can be extracted from a scene using unmixing techniques. Different endmembers extraction methods such as maximum distance (MaxD), SMACC, positive matrix factorization (PMF) and constrained PMF are evaluated. Also different estimators for the number of endmembers are studied. Hyperspectral imagery collected using AISA and AVIRIS as well as simulated data are used in the study. The results show how different algorithms behave as resolution is decreased and the relations between endmembers and abundances extracted at different resolution. We also compare results across methodologies to assess their robustness and limitations.

7695-64, Session 14

Detection and characterization of chemical vapors from hyperspectral imagery by nonlinear optimal estimation

C. M. Gittins, Physical Sciences Inc. (United States)

Matched-filter-based detection of chemical vapor plumes from hyperspectral infrared imagery follows from the presumption of a linear additive signal model. However, examination of the underlying radiative transfer equation (RTE) indicates that while the use of a linear additive signal model is a reasonable approximation when considering an optically-thin plume viewed against blackbody background the RTE is in fact nonlinear. Unfortunately, presumption of a linear additive signal model can significantly degrade plume detection statistics and results in significant errors in estimated chemical vapor column density when plumes are not optically-thin or are viewed against spectrally-complex backgrounds. This paper describes a nonlinear estimation approach which integrates a parameterized signal model based on the RTE with a statistical model for the infrared background. We show results obtained by applying the nonlinear estimation approach to hyperspectral imagery acquired using PSI's Adaptive Infrared Imaging Spectroradiometer-Wide Area Detector (AIRIS-WAD) and compare them with results obtained presuming a linear additive signal model. As plumes become optically-thick, nonlinear estimation yields significantly more accurate estimates of chemical vapor column density and significantly more favorable plume detection statistics than clutter-matched-filter-based and adaptive-subspace-detector-based plume characterization and detection.

7695-65, Session 14

Use of ensemble learning technique for detection/identification of chemical plumes

P. J. Rauss, H. Kwon, U.S. Army Research Lab. (United States)

This presentation examines an ensemble learning approach that uses a number of weak classifiers to improve performance and robustness. The ensemble method is used to identify a specific chemical spectrum in hyperspectral imagery by identifying pixels containing the chemical, locating the plumes extent in the image. Support vector machine (SVM) is used as a weak classifier to perform nonlinear learning on the randomly selected subset of spectral bands from training samples taken from hyperspectral image cubes of a chemical release. Using multiple learning processes conducted in the randomly selected spectral subspaces, the proposed ensemble learning can improve performance and solution generality. Of particular interest is how the effects of the concentration of the gas in the atmosphere affect performance. Algorithm performance on these pixels, as well as stronger concentration pixels with noise added, is investigated as a method of comparing the generality and robustness of the algorithms. Performance results, in the form of receiver operator characteristic curves, show excellent performance when compared to a single SVM using the full spectrum, as well as compared to a simple back propagation of error neural network (BPNN) and orthogonal subspace projection (OSP). Results show the ensemble approach to be considerably more robust than OSP, BPNN or a simple SVM, when all techniques are trained with the clean sensor data. Results from processing a continuum removed HSI cube through these algorithms will also be shown to determine if this approach could alleviate the need for background subtraction to improve signal levels.

7695-66, Session 14

Ensemble learning based on multiple kernel learning for hyperspectral chemical plume detection

H. Kwon, P. J. Rauss, U.S. Army Research Lab. (United States)

Recently, a SVM-based ensemble learning technique has been introduced by the authors for hyperspectral plume detection/classification. The SVM-based ensemble learning consists of a number of sub-SVM classifiers and the decisions from the sub-classifiers are collectively combined together to generate a final ensemble decision. The SVM-based ensemble technique first finds randomly selected spectral feature subspaces. Each sub-classifier then independently conducts its own learning within the corresponding spectral feature space. Therefore, in the SVM-based ensemble technique, multiple learning processes are performed and combining the multiple learning processes in general provides improved ensemble decision over conventional learning.

In combining individual learning results, majority voting has been popularly used along with some aggregating techniques that adaptively weight sub-classifiers based on prior information such as training performance. Most of the current aggregating techniques being used are sub-optimal and data dependent. Techniques that optimally weight the individual decisions from the sub-classifiers are strongly desirable to improve ensemble learning performance.

In the proposed work, a recently introduced kernel learning technique called Multiple Kernel Learning (MKL) is used to optimally weight the kernel matrices of the sub-SVM classifiers. MKL basically iteratively performs L-2 optimization on the Euclidian norm of the hyperplane defined by the weighted kernel matrix followed by L-1 optimization on the weighting coefficients of the individual kernel matrices. Due to L-1 optimization on the weighting coefficients, the optimized weighting coefficients become sparse. The proposed work utilizes the sparse weighting coefficients to combine decision results of the SVM-based ensemble technique. A performance comparison among various aggregating techniques - MKL-based, majority voting, weighted average, etc - will be reported in the final paper.

7695-67, Session 14

Hyperspectral sub-pixel target identification using least-angle regression

P. V. Villeneuve, A. R. Boisvert, A. D. Stocker, Space Computer Corp. (United States)

A novel approach to VNIR hyperspectral target identification is presented based on the Least-Angle Regression (LARS) variable selection and model building algorithm. The problem to be solved is that of accurately identifying a target's primary signature component given a sub-pixel

observation. Traditional matched detectors (AMF, ACE, etc.) perform well at discriminating a target from a random cluttered background, but fail at the task of unambiguously matching an observation with its counterpart in a large spectral library containing thousands of signatures. The LARS model-building algorithm efficiently selects a parsimonious subset of a large ensemble of model terms to optimally describe a particular target observation. The LARS solution technique is a recent addition to the family of model selection algorithms that includes Stepwise Regression, Forward Selection, and Backward Elimination. LARS is particularly well-suited to this problem as it is easily modified to enforce material abundance constraints: positive coefficients that sum to unity. Other approaches generally enforce such constraints in an ad-hoc fashion or use computationally demanding second-order programming solution techniques. LARS enforces these constraints as an inherent property of the model while remaining as computationally efficient as traditional sequential linear least-squares solvers. We demonstrate and quantify sub-pixel material identification performance using simulated target observations tested against large signature libraries.

7695-68, Session 14

Performance evaluation of hyperspectral detection algorithms for subpixel objects

R. DiPietro, MITRE Corp. (United States); D. G. Manolakis, Lincoln Lab. (United States); R. Lockwood, T. Cooley, J. Jacobson, Air Force Research Lab. (United States)

One of the fundamental challenges for a hyperspectral imaging surveillance system is the detection of subpixel objects in background clutter. The background surrounding the object, which acts as interference, provides the major obstacle to successful detection. Two additional limiting factors are the spectral variability of the background and the object to be detected. In this paper, we evaluate the performance of detection algorithms for subpixel objects using a replacement signal model, where the spectral variability is modeled by multivariate normal distributions. The detection algorithms considered are the classical matched filter, the finite target matched filter, and the mixture tune matched filter. Using the replacement model and a geometrical analysis framework, we investigate the relationship of these filters to the optimum likelihood ratio test, the generalized likelihood ratio test, and two-class classifiers. To understand the implications of spectral variability we develop an analytical expression for the ROC curves for the special, but practically important case, where the covariance matrix of object variability is proportional to the covariance matrix of background variability. The algorithms are further compared using simulated and actual hyperspectral imaging data.

7695-69, Session 15

A generalized performance model for spatial interferometric hyperspectral imagers

P. G. Lucey, Univ. of Hawai'i (United States); E. Tsiang, Spectrum Photonics, Inc. (United States)

We have collected performance data on Sagnac interferometer-based LWIR hyperspectral system using three cameras: two with uncooled microbolometer arrays with BAE Systems and Indigo cores, and a cooled HgCdTe array from Sofradir. Using these diverse cameras we have developed a refined performance model that can predict the noise and spectral performance of this class of spatial interferometer. We will present the results of the testing, limitations and remaining uncertainties in the model and outline what data are needed from vendors for focal plane selection.

7695-70, Session 15

Measurement and quantification of scene-change artifacts in Fourier-transform spectroscopy

A. M. Young, K. C. Gross, Air Force Institute of Technology (United States)

Spectral measurement of transient events with a Michelson interferometer is challenging when the scene intensity changes significantly over the measurement timescale. The Fourier transform of an interferogram containing the modulated signal of a temporally-evolving source will be corrupted by scene-change artifacts (SCAs). The magnitude and spectral characteristics of SCAs were studied with an ABB/Bomem MR-154 Fourier-transform spectrometer (FTS) by measuring a controlled, time-varying broadband source. Using an Oriel Q-series incandescent lamp, the FTS operating at 1/cm resolution observed the changing spectral radiance as the lamp's output voltage was smoothly varied during interferogram acquisition. Interferometric measurements were made for various scene-change rates. These measurements were used to validate theoretical expressions for real and imaginary components of the observed spectra. SCA characteristics are described and SCA detection metrics are proposed. Implications for measuring rapidly-evolving combustion systems with Fourier-transform spectroscopy will be discussed.

7695-71, Session 15

Liquid crystal-based hyperspectral image projector

A. Linnenberger, J. E. Stockley, Boulder Nonlinear Systems, Inc. (United States); J. Rice, National Institute of Standards and Technology (United States); H. J. Masterson, Boulder Nonlinear Systems, Inc. (United States)

A hyperspectral image projector (HIP) is introduced that is built with liquid crystal based spatial light modulators (SLM) as opposed to micromirror arrays. The use of an SLM as a broadband intensity modulator presents several benefits to this application. With slight modifications to the SLM design, SLMs can be built for a wide range of spectral regimes, ranging from the ultraviolet (UV) to the long-wavelength infrared (LWIR). SLMs can have a large pixel pitch, significantly reducing diffraction in the mid-wavelength infrared (MWIR) and LWIR. Liquid crystal based devices offer direct analog intensity modulation, thus eliminating flicker from time sequential drive schemes. SLMs allow for an on-axis configuration, enabling a simple and compact optical layout. The design of the HIP system is broken into two parts consisting of a spectral and spatial engine. In the spectral engine a diffraction grating is used to disperse a broadband source into spectral components, where an SLM modulates the relative intensity of the components to dynamically generate complex spectra. The recombined output is fed to the spatial engine which is used to construct two-dimensional scenes. The system is used to simulate a broad range of real world environments, and will be delivered to the National Institute of Standards and Technology as an enabling tool for the development of calibration standards and performance testing techniques for multispectral and hyperspectral imagers. The focus of this paper is on a visible-band HIP system; however, related work is presented with regard to SLM use in the MWIR and LWIR.

7695-72, Session 15

An information measure of sensor performance and its relation to the ROC curve

J. Ahlberg, I. G. Renhorn, N. Wadströmer, Swedish Defence Research Agency (Sweden)

ROC curves are the most frequently used performance measure for detection methods and the underlying sensor configuration. Common problems are that the ROC curve does not present a single number and that it is impossible to discriminate between sensor performance and algorithm performance. To address the first problem, a number of measures are used in practice, like detection rate at a specific false alarm rate, or area-under-curve. For the second problem, we proposed in a previous paper (Ahlberg, J., Renhorn, I., "An information-theoretic approach to band selection," Proceedings of SPIE Vol. 5811, pp. 15-23 (2005)) an information theoretic method for measuring sensor performance. We now relate the method to the ROC curve, show that it is equivalent to selecting a certain point on the ROC curve, and that this point is easily determined.

7695-73, Session 16

Unresolved target detection blind test project overview

J. P. Kerekes, D. K. Snyder, Rochester Institute of Technology (United States)

The development and testing of algorithms for unresolved target detection in hyperspectral imagery requires the availability of empirical imagery with adequate ground truth. However, target deployment and collection of imagery can be expensive, and the resulting data often have limited distribution due to security or propriety concerns. When data are made available, it is usually with full ground truth leading to the possibility of analysts "tuning" their algorithm and reporting optimistic results. There exists an ongoing need for widely available, well ground truthed, independent, and standardized data for the community.

This paper provides an overview and introduction to such a standard blind test data set that has been made freely available along with an automatic scoring system (http://dirsapps.cis.rit.edu/blindtest/). Airborne hyperspectral imagery is provided together with spectral reflectance signatures of several fabric panels and vehicles in the scene. Two images are provided. The self-test image is accompanied by the precise pixel locations in the image for the targets of interest. The blind test image has the targets in different locations and is provided without a pixel truth map.

Since publicizing the data set in 2008, over 100 researchers from around the world have downloaded the data for testing. Numerous uploads of results have occurred with the top 10 for each target published on the web site. Further details on the data, the project, and the results of participants are presented. This paper leads off a special session on the project and is followed by presentations by participants describing their algorithms and results.

7695-74, Session 16

Hybrid algorithms for hyperspectral target detection

V. Roy, Defence Research and Development Canada (Canada)

The combination of multiple algorithms and approaches was investigated as a way to improve performance of hyperspectral target detection. Hybrid algorithms combining stochastic target detection algorithms (CEM, Kelly's) and false alarm mitigation techniques commonly used in linear unmixing approaches to target detection (F-partial test) were designed. When a target was collected in multiple co-registered images over time, we also evaluated the benefit of using temporal information to increase target to clutter ratio.

The performances of these hybrid detection techniques were evaluated using controlled, high spatial resolution reflective hyperspectral imagery collected from commercially available airborne sensors. Results from the exploitation of the Rochester Institute of Technology Blind Test Experiment will be presented.

7695-75, Session 16

Results of GLMM-based target detection on the RIT data set

D. B. Gillis, J. Bowles, U.S. Naval Research Lab. (United States);
E. J. Ientilucci, Rochester Institute of Technology (United States)

The authors have recently introduced the Generalized Linear Mixing Model (GLMM), which extends the traditional Linear Mixing Model by generalizing the concept of an endmember vector to an endmember subspace. This generalization allows us to model the spectral variability that is present in a given class. The model also naturally includes the use of 'target spaces', which have been previously developed to model the variability of at-sensor radiance for a given library spectrum due to atmospheric and illumination uncertainty.

In this paper, we apply the GLMM / target space approach to detecting targets in the recently released RIT test data set. In particular, we give a brief description of the underlying model (including recent improvements to our previously published work), and then present our results of applying this model to the RIT data set.

7695-76, Session 16

Hyperspectral target detection assessment using an online evaluation system

Q. Du, Mississippi State Univ. (United States)

Target detection using hyperspectral imagery has many important applications. Based on the information available, target detection can be conducted in a supervised or unsupervised fashion. In the former case, detection is achieved by "comparing" with a known target signature; in the latter case, detection is accomplished by searching for distinctive pixels based on a certain criterion. In practice, obtaining exact target signatures may be difficult due to in-field spectral variation. Thus, unsupervised target detection may offer special advantage. In this paper, we will evaluate several unsupervised target detection algorithms using the online accessible HyMap data and ground truth provided by Rochester Institute of Technology, and compare with several well-known supervised target detection algorithms. Surprisingly, the overall performance of unsupervised target detection is not inferior to that of supervised target detection.

7695-77, Session 16

Clutter and anomaly removal for statistical target detection

W. F. Basener, Rochester Institute of Technology (United States)

We present an investigation into the underlying mathematical geometry of various statistical target detection algorithms for hyperspectral imagery and introduces a novel detection algorithm which uses anomaly detection to prescreen the computed statistics, improving detection results. We test over sixty statistical target detection algorithms for comparison.

In our test there is no universally best performing algorithm, but there are two clear trends: quadratic detectors such as ACE generally performed better than linear ones such as matched filter and using anomaly detection to prescreen image spectra improved the performance of the quadratic detectors.

7695-78, Session 16

Characterization of physics-based radiative transfer modeling parameters for a blind test airborne hyperspectral dataset

S. Matteoli, Univ. di Pisa (Italy); E. J. Ientilucci, J. P. Kerekes, Rochester Institute of Technology (United States)

This work was motivated by the availability of a new ground truthed hyperspectral data-set, freely accessible to the scientific community for target detection algorithm testing. In our research, we are interested in physics-based approaches to target detection, i.e. those techniques aimed at modeling the radiation transfer within the atmosphere in order to account for atmospheric/viewing/illumination effects. This is, in fact, a crucial aspect in target detection applications, where the available information consists in the sensor-acquired radiance image, and field-measured spectral reflectances of the targets. Properly backing out the aforementioned effects allows detection to be performed in either of the two domains, i.e. radiance or reflectance. As part of our research into the use of physics-based radiative transfer modeling (RTM) for target detection with these data, it was important to accurately analyze the available a-priori information concerning data acquisition, and investigate the value of enhancing this information by making use of freely accessible meteorological and environmental data. In this work, the characterization procedure of the RTM parameters applied with these data is described, and the corresponding RTM parameters thus obtained are reported. A range of variation for some of these parameters were determined as well, in order to allow for a certain degree of variability around nominal conditions (e.g. spatial variability within the scene, non-perfect acquisition condition knowledge, etc.). Target detection results obtained by adopting the RTM parameters attained by the characterization procedure are provided.

7695-79, Session 16

Global, local, and stochastic background modeling for target detection in mixed pixels

M. S. Halper, MITRE Corp. (United States)

As hyperspectral sensors and exploitation methods have evolved, the accuracy of conventional background models has become a limiting factor for high confidence and low false alarm detection of mixed pixel targets. Many common target detection algorithms, such as the Adaptive Coherence/Cosine Estimator (ACE), implicitly use a global background model that assumes the background can be modeled by a single, multivariate Gaussian random variable with additive independent and identically-distributed Gaussian noise. In order to improve the accuracy of the Gaussianity assumptions, a local background model, which models the background as multiple, disjoint Gaussian "clusters", has also been widely considered. This paper introduces a novel stochastic background model that is free from distributional assumptions and accounts for the spectral variability of the background on a pixel-by-pixel basis. The performance of the global, local, and stochastic background models is evaluated on a controlled data set and the tradeoffs associated with each method are discussed.

7695-80, Session 18

NASA's advancements in space-based spectrometry lead to improvements in weather prediction and understanding of climate processes

J. Susskind, NASA Goddard Space Flight Ctr. (United States)

AIRS is a precision state of the art High Spectral Resolution Multi-detector IR grating array spectrometer that was launched into a polar orbit on EOS Aqua in 2002. AIRS measures most of the infra-red spectrum with very low noise from 650 cm-1 to 2660 cm-1 with a resolving power of 2400 at a spatial resolution of 13 km. The objectives of AIRS were to perform accurate determination of atmospheric temperature and moisture profiles in up to 90% partial cloud cover conditions for the purpose of improving numerical weather prediction and understanding climate processes. AIRS data has also been used to determine accurate O3,CO,and CH4 profiles, as well as information about total CO2 column amount. A brief overview of the retrieval methodology used to analyze AIRS observations under partial cloud cover will be presented and sample results will be shown from the weather and climate perspectives.

Assimilation of Quality Controlled temperature soundings determined using AIRS data have been shown to significantly improve global 7 day forecast skill. Anomalies and trends of Outgoing Longwave Radiation (OLR) computed from AIRS products agree perfectly with those measured by CERES and AIRS products explain why global OLR has been decreasing over the last few years.

The excellent noise performance of AIRS at high frequencies is critical to the achievement of the outstanding results being obtained using AIRS data. NASA has a design for a further advanced IR sounder with spectral and noise performance superior to those of AIRS at a spatial resolution of 1 km from Low Earth Orbit. Such an instrument would lead to further improvements in the ability to predict weather, explain climate phenomena, and monitor trace gas distributions, especially pollutants.

7695-81, Session 18

Infrared land surface emissivity spectra retrieval from hyperspectral infrared instrument observations

H. Sun, Perot Systems Government Service (United States); W. W. Wolf, L. Zhou, National Oceanic and Atmospheric Administration (United States); Z. Cheng, Perot Systems Government Service (United States); C. D. Barnet, M. D. Goldberg, National Oceanic and Atmospheric Administration (United States)

The operational retrieval of Hyperspectral infrared Instrument (AIRS/IASI/CrIS) need the high spectral resolution land surface emissivity dataset as a first guess. An regression algorithms was developed and applied for AIRS retrieval in NOAA. This algorithms calculate emissivity on frequency hinge points with regression equation trained from simulated radiance and the surface emissivity used in simulation. The hinge points emissivity result is then interpolated to high spectral resolution linearly. This algorithm provide important support for the AIRS retrieval system, but the result analyzing also show problems existed and improvements are required for both the algorithms training data set and interpolation processing. In this paper, The regression algorithms used for CrIS and IASI retrieval are developed with the improved training data set. The high spectral resolution emissivity is derived from a combination knowledge of the regression result on hinge point and high spectral resolution laboratory measurement result.

7695-82, Session 18

Estimating atmosphere parameters in hyperspectral data

J. Ahlberg, Swedish Defence Research Agency (Sweden)

We address the problem of estimating atmosphere parameters (temperature, water vapour content) from data captured by an airborne thermal hyperspectral imager, and propose a method based on direct optimization. The method also involves the estimation of object parameters (temperature and emissivity) under the restriction that the emissivity is constant for all wavelengths. Certain sensor parameters can be estimated as well in the same process. The method is analyzed with

respect to sensitivity to noise and number of spectral bands. Simulations with synthetic signatures are performed to validate the analysis, showing that estimation can be performed with as few as 10-20 spectral bands at moderate noise levels. More than 20 bands does not improve the estimates. The proposed method is also extended in order to incorporate additional knowledge, for example measurements of atmospheric parameters and sensor noise.

7695-83, Session 18

Atmospheric compensation of thermal infrared hyperspectral imagery with the emissive empirical line method and the in-scene atmospheric compensation algorithms: a comparison

R. J. DiStasio, Jr., MITRE Corp. (United States); R. G. Resmini, National Geospatial-Intelligence Agency (United States)

The in-scene atmospheric compensation (ISAC) algorithm of Young et al. (2002) [1] (and as implemented in the ENVI® software system [2] as 'Thermal Atm Correction') is commonly applied to thermal infrared multi- and hyperspectral imagery (MSI and HSI, respectively). ISAC estimates atmospheric transmissivity and upwelling radiance using only the scene data. The ISAC-derived transmissivity and upwelling radiance are compared to those derived from the emissive empirical line method (EELM), another in-scene atmospheric compensation algorithm for thermal infrared MSI and HSI data. EELM is based on the presence of calibration targets (e.g., panels, water pools) captured in the spectral image data for which the emissivity and temperature are well known at the moment of MSI/HSI data acquisition. EELM is similar in concept to the empirical line method (ELM) algorithm commonly applied to visible/near-infrared to shortwave infrared (VNIR/SWIR) spectral imagery and is implemented as a custom ENVI® plug-in application. Both ISAC and EELM are in-scene methods and do not require radiative transfer modeling. ISAC and EELM have been applied to airborne longwave infrared (LWIR; ~7.5 micrometers to ~13.5 micrometers) HSI data; EELM has also been applied to simulated LWIR data. Captured in the imagery are calibration panels and/or water pools maintained at different temperatures facilitating the application of EELM. Overall, the atmospheric compensation parameters derived from the two methods are in close agreement: the EELM-derived ground-leaving radiance spectra generally contain fewer residual atmospheric spectral features. ISAC sometimes produces smoother ground-leaving radiance spectra than EELM. Nonetheless, the agreement is viewed as validation of ISAC. ISAC is an effective atmospheric compensation algorithm that is readily available to the remote sensing community in the ENVI® software system. Thus studies such as the present testing and comparing ISAC to other methods are important. The ISAC and EELM algorithms are discussed as are the airborne LWIR and simulated data to which they are applied. Also presented are analyses and comparisons of the retrieved transmissivity and upwelling radiance terms. [1] J. Geophys. Res., v. 107, no. D24, 4774, doi: 10.1029/2001JD001266, 20 p. [2] http://www.ittvis.com/ProductServices/ENVI.aspx

Conference 7696A: Automatic Target Recognition XX

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7696A-02, Session 1

A robust target tracking algorithm for FLIR imagery

A. L. Chan, U.S. Army Research Lab. (United States)

The attempt to detect and track moving targets in FLIR imagery is often hampered by a number of phenomenological challenges associated with FLIR sensors. These challenges include reversed polarity of the same targets in different seasons, varying target-to-background contrast as the ambient temperature changes over the course of a day, and often spotty heat emissivity from a given large target. In this paper, a robust target tracking algorithm is proposed to achieve a better tracking performance by overcoming some of these difficulties. The proposed algorithm is based on a number of disjoint intermediate background models that are subsequently and intelligently combined to form an accurate and dynamic representation of the current background. On the other hand, the signatures of moving targets are captured and enhanced through a set of image filters, while the next movements of these targets are reasonably estimated using a set of kinematic predictors. By integrating the effective target detection method with the robust background modeling process, an excellent target tracking performance can be achieved. A large and carefully ground-truthed FLIR video dataset, which is called the ARL Force Protection Surveillance System (FPSS) dataset, is used to examine the performance of this target tracking algorithm. Initial results have shown a very accurate tracking performance at a rather low false alarm rate.

7696A-03, Session 1

Track uncertainty resolution through confirmation of identity using the distance classifier correlation filter

B. Walls, Areté Associates (United States)

Critical to a large portion of mission scenarios within the intelligence, surveillance, and reconnaissance (ISR) sensor community is the challenge to ensure designated targets of interest are reliably tracked in dynamic environments. Current generation trackers frequently loose track when targets become temporarily obscured, shadowed, or is in close proximity to other objects. In this paper we propose and demonstrate a generic confirmation of identity module that is based on the Distance Classifier Correlation Filter (DCCF) and is applicable to a variety of tracking technologies. The prevailing idea of this technique is that during a trackers valid track phase, learning exemplars are provided to a filter building process and templates of the tracked targets are created real-time online. Differences in orientation are handled through the creation of a database of synthetic views using real target views and image warping techniques. After obscuration and/or during periods of track ambiguity, each new candidate track is matched against the prior valid track(s) using DCCF matching to resolve uncertainty.

7696A-04, Session 1

Shape and motion-fused multiple flying target recognition and tracking

L. Kovács, Z. Szlávik, Á. Utasi, Computer and Automation Research Institute (Hungary)

This paper presents an automatic approach for camera/image based detection, recognition and tracking of flying objects (planes, missiles, etc.). The method detects appearing objects, and recognizes re-appearing targets. It uses a feature-based statistical modeling approach (Hidden Markov Model) for motion-based recognition, and an image feature (e.g. shape) based indexed database of pre-trained object classes, suitable for recognition on known and alerting on unknown objects. The method can be used for detection of flying objects, recognition of the same object category through multiple views/cameras and signal on re-occurring or on new object appearances.

7696A-14, Session 1

Formation and propagation of noise fields in a dispersive medium

L. Cohen, Hunter College (United States)

There are many mechanism that produce noise in the ocean and while some are stationary many are not. We address and solve the following problem: Suppose a noise field with known statistics is generated in a region or point in space, then, what are the statistics at a later time and at an arbitrary point in space where the propagation is in a dispersive medium. We show that considerable insight may be achieved if the problem is analyzed in phase-space where the phase-space distribution may be time-frequency or position-wavenumber. We obtain an exact differential equation for propagating noise fields and show that it leads to effective approximate methods for practical calculations.

A number of examples will be given and also application to a train of pulses relevant to reverberation and clutter is also discussed.

7696A-05, Session 2

New paradigm of learnable computer vision algorithms based on the representational MDL principle

A. S. Potapov, A. E. Puysha, I. A. Malyshev, S.I. Vavilov State Optical Institute (Russian Federation); A. N. Averkin, Saint-Petersburg State Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Learning is one of the most crucial components that is necessary in orde to increase generality, flexibility, and robustness of computer vision systems. At present, image analysis algorithms adopt particular machine learning methods, however, this leads to rather superficial learning. We present a new paradigm for constructing essentially learnable computer vision algorithms. Learning is interpreted as optimization of image representations. Notion of representation is formalized within information-theoretic framework. Optimization criterion is derived from the minimum description length (MDL) principle, which is widely used for model selection. Adaptation of the MDL principle in computer vision has been receiving increasing attention in the recent years. However, this principle has been applied in heuristical way. The reason of gap between theoretical MDL principle and its practical applications is revealed in our paper. We deduced representational MDL (RMDL) principle that fills this gap. The RMDL principle gives criteria both for optimal model selection of a single image within given representation, and for optimal representation selection of an image sample. Thus, it can be used for image representation optimization in computer vision systems functioning within specific environment. Adequacy of selection of representations using the RMDL principle was validated on a number of segmentation-based representations applied to different object domains (aerospace optical, SAR, indoor, and OCT images). A method for learning local features was developed based on automatic selection of representations. This method outperformed some popular methods with static (prior) representations such as SIFT. Thus, the paradigm can be admitted as promising.

7696A-06, Session 2

A two-stage statistical model for underwater object recognition using hidden Markov model and feedback mechanism

Y. Zheng, Alcorn State Univ. (United States); G. Chen, DCM Research Resources, LLC (United States); R. S. Lynch, Naval Undersea Warfare Ctr. (United States); E. P. Blasch, Air Force Research Lab. (United States)

The goal of the proposed research is to improve the accuracy and robustness of underwater object recognition. Accuracy means the target recognition rate with a reasonable number of false alarms, whereas the robustness means the recognition adaption to various operating conditions such as environmental, target, and sensor noise levels. We propose a two-stage statistical model for underwater object recognition using a hidden Markov model (HMM) and a feedback mechanism. The feedback mechanism adds the misclassified objects into the labeled database (used as knowledge base) such that the HMM models can be automatically retuned with the updated knowledge base for enhanced target recognition through adaption and learning.

7696A-07, Session 2

The development of adaptive image kernels for maximizing vision quality

S. F. Page, D. C. Bamber, Waterfall Solutions Ltd. (United Kingdom); P. K. Kimber, SELEX GALILEO (United Kingdom)

This paper presents a novel image noise reduction technique based on the use of adaptive image filter kernels that preserve important salient image features. The eccentricity, orientation and scale of the kernels are automatically adapted according to local image content measures. It is demonstrated that the approach provides superior noise reduction over conventional adaptive and non-adaptive approaches according to various performance measures, and example results are presented herein. A novel method to reduce the computational complexity of the technique without compromising performance is proposed, and details of a high-speed implementation of the technique on a Graphical Processing Unit are presented.

7696A-08, Session 2

Multi-class target recognition based on adaptive feature selection

Y. Wang, N. Sang, T. Zhang, Huazhong Univ. of Science and Technology (China)

Most of the multi-class target recognition are based on training, i.e., train a specific classifier model with a lot of target samples seperated from background. However, in many target recognition tasks, it is difficult to get enough samples, and make them cover the whole feature space. Another drawback of this kind of method is that target has already been segmented from scene, which leads to the difficult task of segmentation. Under such circumstance, analyzed feature model is always used, we can analyze a target and its background, find out stable features, the feature model can be used both in detection and recognition, and no precise target segmentation is necessary. But in multi-class target recognition, such analyzed feature models are not efficient. In this paper, a new approach of multi-class target recogniton is proposed. A multi-layer analyzed feature model are built for each class, the leaf layer of which are basic features such as brightness, local contrast, and gabor features etc. Such multi-layer feature models of each class are then integrated to build up a multi-class feature model, which are based on shared features among classes. In order to make the recognition process efficient, we adopted the idea of attention. In human vision, attention is

used for information selection, including feature selection. As in human vision, in each layer of the integrated feature model, the most salient and stable feature are selected first, and then the less ones, which reduces the required computation for separate one class from others significantly. Experiments demonstrated the approach proposed is efficient in computation and is adpative to scene variation.

7696A-09, Session 3

Modified approach to signal detection in adaptive signal processing

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

The well-known general problem of signal detection in background interference is addressed for situations where a certain statistical description of the interference is unavailable, but is replaced by the observation of some secondary (training) data that contains only the interference. For the broad class of interferences that have a large separation between signal- and noise-subspace eigenvalues, we demonstrate that the generalized detectors, which are constructed based on the generalized approach to signal processing in noise and employed by adaptive signal processing techniques, using a diagonally loaded sample covariance matrix or a fast maximum likelihood estimate, have significantly better detection performance in comparison with the traditional generalized likelihood ratio test and adaptive matched filter detection techniques, which use a maximum likelihood covariance matrix estimate. To devise a theoretical framework that can generate similarly efficient detectors, two major modifications are proposed. First, two-sample decision rule for the generalized detector takes a great advantage of an a priori assignment of different functions to the primary and secondary (reference) data, unlike the traditional generalized likelihood ratio test decision-making rule (the Kelly rule) was derived without this. Second, instead of maximum likelihood estimates of the missing parameters in both the generalized likelihood ratio test and adaptive matched filter detectors, we adopt expected likelihood estimates that have likelihood within the range of most probable values generated by the actual interference covariance matrix. A Gaussian model of fluctuating target signal and interference is used in this investigation. We demonstrate that, even under the most favorable loaded sample-matrix inversion conditions, the theoretically derived expected likelihood generalized detector techniques (where the loading factor is chosen from the training data (reference independent and uncorrelated sample)) gives us a great superiority in the detection performance in comparison with loaded adaptive matching filter technique with a proper a priori data-invariant loading factor. For the least favorable conditions, our method may be interpreted as an intelligent (data-dependent) method for selecting the loading factor.

7696A-10, Session 3

Prediction and flexible modeling for automatic target recognition

A. U. Sokolnikov, Visual Solutions and Applications (United States)

The reliability of the data analysis from sensors is the main factor for making the right decisions for target recognition. Obviously, the reliability depends on the quality of the sensors and processing electronics. However, the cases where the target is clearly determined are not numerous. More often, we receive partial and distorted images from the sensors employed. Thus, we have a task of determining the correct initial image that was distorted by various factors before and after it was detected by sensors. The proposed approach is an adaptive intelligent system that uses algorithms, renewable data base as well as the possibility of changing the detection system's parameters and modes of operation depending on the signal received from the identified objects.

7696A-11, Session 3

Multi-frame correlation filtering of targets from two different classes with a single QCF

A. F. Rodriguez, B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

Distortion-tolerant correlation filter (CF) methods have been applied to many video-based automatic target recognition (ATR) applications. The Quadratic CF (QCF) is designed to maximize the separation of two different classes. This filter is usually trained with images of the target of interest for one class and images of clutter and shifted versions of the target for the other class. In this paper we show that we can perform ATR on different targets from two different classes with one QCF filter. We use a simplified version of Kerekes and Kumar's recently introduced Multi-Frame CF (MFCF) that combines information from the current correlation output with previous correlation outputs to suppress false peaks in non-target regions. Additionally the training and testing images are pre-whitened to increase peak sharpness to improve recognition. Preliminary results show the filter correctly detecting and tracking tanks from two different classes.

7696A-12, Session 3

Quadratic mutual information for dimensionality reduction and classification

D. Gray, Univ. of Florida (United States)

A research area based on the application of information theory to machine learning has attracted considerable interest in the last few years. This research area has been coined information-theoretic learning within the literature. In this paper we apply elements of information-theoretic learning to the problem of Automatic Target Recognition. A number of researchers have previously shown the benefits of designing classifiers based on maximizing the mutual information between the class data and the class labels. Following prior research in information theoretic learning, in the current results we show that quadratic mutual information, derived using a special case of the more general Renyi's entropy, can be used for classifier design. In this implementation, a simple linear subspace projection classifier is formulated to find the optimal projection weights such that the quadratic mutual information between the class data and the class labels is maximized. This subspace projection accomplishes a dimensionality reduction of the raw data set wherein information about the class membership is retained while irrelevant information is discarded. A subspace projection based on this criterion preserves as much class discrimination as possible within the subspace. For this paper, laser radar images and public-release MSTAR images are used to demonstrate the results. Classification performance against these data sets is compared for a PCA-based subspace classifier, a support vector machine classifier, and the quadratic mutual information classifier.

7696A-01, Session 4

Occlusion handling based on particle filter in surveillance system

X. Pan, X. Chen, Beijing Univ. of Posts and Telecommunications (China)

Object tracking is an essential component of an intelligent video surveillance system. For object tracking, occlusion handling is one of the most challenging problems. Because during occlusion, only part of the object is visible and the features of the object become ambiguous. Among various tracking algorithms, particle filtering (PF) is a robust and accurate one for different applications. It also allows data fusion from different sources due to its inherent property without increasing the dimension of the state vector. In this paper, a new approach based on particle filter is presented for tracking object accurately and steadily when the target encountering occlusion in video sequences. First, the object pixels are classified as foreground and background for each frame using background subtraction. Our approach combines the foreground region with the particle initialization and similarity measure step to lower the background distraction. Second, a set of cues including a motion estimation model, an elliptical shape model, a spatial-color mixture of Gaussians appearance model, and an edge orientation histogram model extracted by Canny algorithm is fused and modeled by a data likelihood function. Then, a particle filter algorithm is used for tracking and the particles are weighted and re-sampled based on the fusion of the cues. Results from simulations and experiments with real video sequences show the effectiveness and robustness of our approach for tracking people under occlusion conditions.

7696A-13, Session 4

Doppler spectral analysis for two-dimensional time-evolving nonlinear sea surfaces

X. Li, X. Xu, BeiHang Univ. (China)

Modeling of the electromagnetic (EM) scattering properties from two-dimensional (2-D) time-varying sea surfaces is a particularly complicated problem. The intricate structure of surface waves and the scattering models noticeably influence the simulated radar signals. Scattering calculations and Doppler spectra from the sea surfaces have been intensively studied, experimentally as well as theoretically in the past. However, to author's knowledge, rare results can be found in literatures for Doppler spectra from two-dimensional time-evolving nonlinear sea surfaces.

In this work we focus on the Doppler spectra characteristics from 2-D time-varying nonlinear sea surfaces. Based on Creamer's sea surface model, the first-order small slope approximation (SSA) method is applied to solve the 3-D scattering problem. The Doppler spectra of the backscattered signals from 2-D time-varying sea surfaces are studies for different incident angles (from normal to low grazing) as well as wind directions (from upwind to crosswind). The impacts of the nonlinearity on the Doppler shifts and spectral widths of backscattered signals are analyzed.

The paper consists of four sections: 1. Introduction; 2. Two-Dimensional Nonlinear Time-Varying Sea Surface Realization; 3. Doppler Spectral Calculation; 4. Numerical Results and Analysis; and references.

7696A-15, Session 4

Phase-space scattering and noise

L. Cohen, Hunter College (United States)

We describe how joint position-wave number distributions can be used to study scattering. We show that such joint representations are appropriate because indeed scattering involves changes in position and momentum and hence a joint representation gives considerable insight an and is also mathematically advantageous. We also consider the scattering from randomly distribution point scatterers and discuss how the resulting noise field propagates.

We have used various distributions and will show that different distributions behave differently in this regard and we are now studying practical implementation problems to calculate the scattered waves. Also, a number of approximation schemes will be presented and compared to the exactly solvable examples.

7696A-16, Session 4

Optimal time and frequency domain waveform design for target detection

B. Hamschin, P. J. Loughlin, Univ. of Pittsburgh (United States)

Some marine mammals as well as bats are known to emit sophisticated waveforms while searching for objects or hunting prey. Some dolphins have been observed to change their sonar pulse depending on the environment. Incorporating these strategies into sonar and radar waveform and receiver design has become an active area of research. In this paper, we explore the application of an optimal waveform design scheme recently given by Kay, for detection of elastic objects. We examine the benefits of optimal waveform design versus transmitting a linear FM waveform, as well as performance loss suffered by assuming a point target. The optimization approach designs the power spectrum of the transmit waveform and, accordingly, there is an unlimited number of ``optimal'' transmit waveforms with the same power spectrum. We propose a time domain optimization criterion to obtain the transmit waveform with the optimal power spectrum and the smallest possible duration, as well as the waveform with the optimal power spectrum and the longest possible duration. The former waveform allows higher ping rates, but necessarily has higher time domain peak-to-average power, while the latter waveform has lower time domain peak-to-average power and lower ping rates. A method to obtain waveforms that are a blend of these two extremes is also presented, allowing a smooth trade-off between ping rate and peak power.

7696A-17, Session 4

Estimation of the Doppler effect modeled as continuously varying time delay

D. J. Nelson, National Security Agency (United States)

We present a method for estimating relative delay and Doppler effects of a received signal and a reference signal. The method may be applied to the problem of estimating target range and radial velocity of a moving target from a comparison of the transmitted and received signals. The method may equally well be applied to the problem of estimating the location of a transmitter from a comparison of signals received by two or more moving receivers. Unlike conventional methods in which Doppler effects are modeled as a frequency translation of the received signal, we assume the correct Doppler model in which the received signal differs from the transmitted signal by a time-varying delay function. Under this correct model, Doppler velocity is estimated as the derivative with respect to time of the time-varying delay function. We demonstrate that the instantaneous velocity is proportional to the instantaneous phase velocity of the correlation function. We estimate the instantaneous delay function from the correlation phase velocity by a recursive implementation that may be estimated with as few as two taps. The delay function may then be fit to a polynomial that represents the instantaneous delay, velocity, acceleration, and higher order derivatives, if desired.

7696A-18, Session 4

Classification of radar data by detecting and identifying spatial and temporal anomalies

M. Väilä, J. Jylhä, I. Venäläinen, H. Perälä, M. H. Ruotsalainen, A. J. E. Visa, Tampere Univ. of Technology (Finland)

For some time now, applying the theory of pattern recognition and classification to radar signal processing has been a topic of interest in the field of remote sensing. Efficient operation and target indication is often hindered by the signal background, which can have overlapping properties with the interesting signal. In many surveillance applications, there is a need for detecting and recognizing different types of targets among such clutter with little human effort. We propose an algorithm for surveillance radar signal classification of each resolution cell, the spatiotemporal unit of the radar data, in a heterogeneous clutter background. The classification is done based on the time history of the response behavior in a resolution cell and correlation to its spatial surroundings. Cells are analyzed individually on each Doppler band. If the newest sample on any band differs statistically from its time history, the cell is determined anomalous. The normal cells are classified as noise, ground clutter or volume clutter based on their strength on each

Doppler band and the spatially adjacent cells. The anomalous cells are measured with a longer coherent illumination. Based on the decorrelation behavior and spectrum, they are classified as, for instance, volume clutter, an airplane or a helicopter. The algorithm is tested with both experimental and simulated radar data of a high range resolution radar. The experimental radar data has been recorded in the Finnish landscape.

7696A-19, Session 5

Using video for multi-view object categorization in security systems

M. Humera Noor, NED Univ. of Engineering and Technology (Pakistan); S. N. Yusuf, Sir Syed Univ. of Engineering & Technology (Pakistan); S. H. Mirza, Usman Institute of Technology (Pakistan)

Recognizing objects of interest in an environment is one of the most important aspects of security applications. Many techniques exist focusing on object categorization; however, most of them consider just a single viewpoint. This leads to increased false alarms as multiple objects look alike from one viewpoint and are totally different from other view. Hence, it is important to consider multiple views of the target simultaneously while categorizing. This paper presents a strategy for multi-view object categorization on the basis of video. The temporal and spatial information of videos is utilized to effectively categorize the objects from multiple views.

In this work, given a set of images of an object category, independent graphical models are generated for each object using underlying geometry and pruned using morphing. Next, the model is evolved by combining the independent graphs, where each node represents different instances from same viewpoint and links exist between adjacent viewpoints. Finally, a classifier is trained for each node. The algorithm is strong in that it does not require camera calibration and doesn't place any constraint on object and/or camera trajectory. Also, it eliminates the need of manually aligning the corresponding viewpoints across the different instances of the object. Finally, the motion continuity in video is exploited to perform matching based on video clip rather than the conventional single image. It is demonstrated using datasets from VIVID (DARPA), NASA and PASCAL that the results thus obtained are much more robust with a precision of 85.73% as against 76.14% for single image.

7696A-20, Session 5

Toward a robust 3D model-based ground target classification system for airborne platforms

W. Ensinger, C. Stahl, P. Knappe, EADS Deutschland GmbH (Germany)

Future target acquisition missions of military aircraft require a robust classification and tracking system of ground targets. Together with onboard ATD systems, this would enable a fast Find, Fix, Track cycle for airborne platforms using imaging sensors like EO/IR, SAR etc. For EO/IR image sequences, a progressive 3D matching and pose estimation algorithms suite was developed at EADS internal research in the past which is based on CAD model rendering, matching of model and image features and pose estimation. The available 3D matching and pose estimation algorithmic modules cover traditional approaches e.g. template matching and modern approaches like mutual information. This paper describes the achieved work towards a 3D model ground target classification system which is robust wrt. requirements of military aircraft missions. Robustness requirements are formulated concerning sensors, scenarios, object classes and environmental conditions The algorithm suite is evaluated wrt. the derived robustness criteria's using a systematically constructed set of image sequences which range from pure synthetic via laboratory conditions towards real-world recordings.

The systematic down selection of different algorithm variants is depicted and the selected 3D ground target classification method is evaluated in a rapid prototyping environment using graphics cards acceleration techniques. The outlook shows possible extensions of the system e.g. tracking and hypothesis management modules as well as the necessary steps to implement and integrate the selected method into a realtime embedded onboard mission system.

7696A-21, Session 5

Workbench for 3D target detection and recognition from airborne motion stereo and ladar imagery

S. Roy, Defence Research and Development Canada (Canada); S. Se, MacDonald, Dettwiler and Associates Ltd. (Canada); J. Maheux, Defence Research and Development Canada (Canada); C. Nadeau, MacDonald, Dettwiler and Associates Ltd. (Canada); V. Larochelle, J. Fournier, Defence Research and Development Canada (Canada)

3D imagery has a well-known potential for improving situational awareness and battlespace visualization by providing enhanced knowledge of uncooperative targets. This potential arises from the numerous advantages that 3D imagery has to offer over traditional 2D imagery, thereby increasing the accuracy of automatic target detection (ATD) and recognition (ATR). Despite advancements in both 3D sensing and 3D data exploitation, 3D imagery has yet to demonstrate a true operational gain, partly due to the processing burden of the massive dataloads generated by modern sensors. In this context, this paper describes the current status of a workbench designed for the study of 3D ATD/ATR. Among the project goals is the comparative assessment of algorithms and 3D sensing technologies given various scenarios. The workbench is comprised of three components: a database, a toolbox, and a simulation environment. The database stores, manages, and edits input data in various formats such as point clouds, video, still imagery frames, CAD models, and metadata. The toolbox features data processing modules, including range data manipulation, surface mesh generation, texture mapping, and a shape-from-motion module to extract a 3D target representation from video frames or from a sequence of still imagery. The simulation environment includes synthetic point cloud generation, 3D ATD/ATR algorithm prototyping environment and performance metrics for comparative assessment. In this paper, the workbench components are described and preliminary results are presented. Ladar, video and still imagery datasets collected during airborne trials are also detailed.

7696A-22, Session 5

Threat detection and tracking using 3D FLASH ladar data

C. A. Gronwall, G. Tolt, D. Karlsson, J. Rydell, H. Esteki, Swedish Defence Research Agency (Sweden); E. E. Armstrong, OptiMetrics, Inc. (United States); J. Woods, Air Force Research Lab. (United States)

Laser-based 3D sensors measure range with high accuracy and allow for detection of objects behind various types of occlusion, e.g., tree canopy. Range information is valuable in detection of small objects that typically are represented by 5-10 pixels in the data set. Range information is also valuable in tracking problems when the tracked object is occluded under parts of its movement and when there are several objects moving around in the scene. In this paper, on-going work on detection and tracking are presented. Detection of partly occluded vehicles, humans and land mines are shown. Two detection approaches have been tested; one is based on fusing a set of features, i.e., detection cues. Among the considered analysis methods we find local surface detection, shadow analysis and height-based detection. The other approach is based on independent

component analysis (ICA). The benefits with range information are analyzed and discussed using simulation-based data and outdoor measurements with a 3D FLASH LADAR sensor. Results on tracking of vehicles and humans are also presented.

7696A-23, Session 6

ATR via sparse representations

K. Estabridis, Naval Air Warfare Ctr. Weapons Div. (United States)

Automatic target recognition (ATR) based on the emerging technology of Compressed Sensing (CS) can considerably improve accuracy, speed and cost associated with this type of systems. We have developed an image based ATR algorithm built upon the theory of CS that performs target recognition in the compressed domain while maintaining robustness. The algorithm is rotational and scale independent . Compressed dictionaries (A) are built to include rotational information for a scale of interest. The algorithm seeks to identify y(test sample) as a linear combination of the dictionary elements : y=Ax, where A R^nxm(n<<m) and x is a sparse vector (most entries are zeros) whose non-zero entries encode the identity of y. The signal x will be sparse with respect to the dictionary A as long as y is a valid target. The algorithm is capable of rejecting invalid targets that are not part of the dictionary. The recognition problem is solved by finding the sparse-solution to the undetermined system y=Ax via L1 minimization techniques.

Visible and MWIR imagery collected by the Army Night Vision and Electronic Sensors Directorate (NVESD) was utilized to test the algorithm. Current results show a recognition rate above 90% with a corresponding false alarm rate of 6.25% for IR targets at a range of 3Km for all aspect angles.

7696A-24, Session 6

Using compressive imaging as a fast class formation method in automatic target acquisition

C. F. Hester, K. K. Dobson, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States)

Subspace projection is an effective and established way to form classes in the Automatic Target Acquisition (ATA) problem. Class subspace formation is viewed in this paper as an overspecified Fh = u problem. Recent advances in compressive sensing show that this problem can be solved for sparse matrices via iterative techniques. Convergence of these techniques is aided by a metric induced by an appropriately selected norm. In this paper we will use infrared data to show this rapid class formation and to compare convergence for two norms. Based on this class formulation a new method for ATA solution will also be demonstrated.

7696A-25, Session 6

Sparsity inspired automatic target recognition

N. M. Nasrabadi, U.S. Army Research Lab. (United States); V. M. Patel, R. Chellappa, Univ. of Maryland, College Park (United States)

Although the improvement in Automatic Target Recognition (ATR) performance using multiple sensors has been validated in a sensor fusion framework, the computational load involved in processing all the sensor data has often hampered the development of real-time ATR algorithms. In this paper, we develop a framework for using only the needed data for ATR algorithms using the recently developed theory of sparse representations, also known as compressive sensing (CS). We show how sparsity can be helpful for efficient utilization of data, with the possibility of developing real-time, robust target classification. We verify

the efficacy of the proposed algorithm using confusion matrix on the well known Comanche FLIR data set consisting of ten different military targets at different orientations.

7696A-27, Session 7

Polynomial chaos theory for performance evaluation of ATR systems

M. D. DeVore, A. J. Bateman, Barron Associates, Inc. (United States)

The development of a more unified ATR theory has received considerable attention over the last several years from individual researchers, working groups, and workshops. One of the major benefits expected to accrue from such a theory is an ability to analytically derive performance metrics that accurately predict real-world behavior. Numerous sources of uncertainty affect the actual performance of an ATR system, so direct calculation has been limited in practice to a few special cases because of the practical difficulties of manipulating arbitrary probability distributions over high dimensional spaces. This paper demonstrates an alternative approach for evaluating ATR performance based on a generalization of Norbert Wiener's polynomial chaos theory. Through this theory, random quantities are expressed not in terms of joint distribution functions but as convergent orthogonal series over a shared random basis. This form can be used to represent any finite-variance distribution and can greatly simplify the propagation of uncertainties through complex systems and algorithms. The paper presents an overview of the relevant theory and illustrates how it can be applied to determine probabilities of error in multi-target classification problems as well as the distribution of position errors from target tracking algorithms.

7696A-28, Session 7

Anomaly detection in wavelet domain for longwave FLIR imagery

N. M. Nasrabadi, A. Mehmood, U.S. Army Research Lab. (United States)

In this paper a new anomaly detection technique for mid-wave as well as long-wave IR imagery is developed. The proposed technique consists of a combination of the well known RX anomaly detector and a two-dimensional wavelet transform. Each input image of size 480x720 pixels is first wavelet decomposed uniformly into 64 equal sub-bands of size 60x90 pixels. All these sub-bands are then rearranged into a cube of size 64x60x90 pixels such that the first band represents the base-band and the subsequent bands represent the sorted higher frequency sub-bands. The high frequency bands are sorted (based on their sub-band variance) before concatenation. Each pixel in the cube now contains all the spatial frequency information at that particular location. A well known anomaly detection technique so called RX algorithm (equivalent to a Mahalanobis distance) which is mainly used in hyperspectral anomaly detection is now applied on this cube using a double-window approach. In double window approach two concentric windows (dual window) centered at each test pixel are opened creating two disjoint regions- an inner window region (IWR) and an outer window region (OWR). The size of the IWR is generally set to fully enclose the target

In RX algorithm the background clutter is represented as a multivariate Gaussian distribution with a covariance matrix which is calculated from the pixels in the OWR of a dual rectangular window approach. Therefore, the size of the OWR is set such that a meaningful covariance matrix for RX algorithm can be evaluated. RX algorithm is applied on the whole cube having all the sub-bands as well as on a cube consisting of only the significant concatenated bands. Using RX on the concatenated sub-bands the inter-correlation between the sub-bands are exploited in the RX decision process.

Experimental results are provided for a data base of 465 IR images. ROC plots are shown for the RX algorithm. ROC plots show that the best performance is obtained by using only the top 10-15 significant bands.

The reason behind this improvement is that the high frequency bands are corrupted with the sensor noise. Also the proposed technique is compared with the standard Constant False Alarm Rate (CFAR) using double window approach on the original IR image.

7696A-29, Session 7

Rotational-invariant wavelet target signatures

W. D. Reynolds, Jr., D. S. Campbell, ITT Corp. (United States)

This research paper investigates the use of the wavelet transform to extract spatially-invariant wavelet-based shape signatures for automatic target recognition. Target signatures based on shape information can be generally categorized as either contour-based or region-based. The wavelet-based shape signatures facilitate detection and localization of important edge and texture information aiding in discrimination between targets.

To demonstrate the advantages of both edge and region information, we present an approach that combines region-based shape methods and the wavelet transform for generating target signatures. Our approach generates a rotationally invariant class of wavelet signatures based on the ground pixel coverage of the target that determines the region-of-interest (ROI) in the wavelet domain. This process results in a multiresolution representation of the target, and provides a hierarchical approach to target signature-matching. We demonstrate this methodology using signatures from aircraft targets and utilizing the Angular Radial Transform (ART) as the region-based shape signature. Region-based signatures are shown more robust than contour-based signatures in the presence of noise and disconnected target regions providing greater confidence in target identification. Our research results show the value of combining the rotational invariance of the ART signatures with the localization property of the wavelet transform.

7696A-30, Session 7

Human-guided visualization enhances automated target detection

J. M. Irvine, The Charles Stark Draper Lab., Inc. (United States)

Automated target cueing (ATC) can assist analysts with searching large volumes of imagery. Performance of most automated systems is less than perfect, requiring an analyst to review the results to dismiss false alarms or confirm correct detections. This paper explores methods for improving the presentation and visualization of the ATC output, enabling more efficient and effective review of the detections flagged by the ATC. The techniques presented in this paper are applicable to a wide range of search problems using data from different sensors modalities. The information available to the computer increases as ATC detections are either accepted or rejected by the analyst. It is often easy to confirm obviously correct detections and dismiss obvious false alarms, which provides the starting point for the automated updating of the visualization. In machine learning algorithms, this information can be used to retrain or refine the classifier. However, this retraining process is appropriate only when future sensor data is expected to closely resemble the current set. For many applications, the sensor data characteristics (viewing geometry, resolution, clutter complexity, prevalence and types of confusers) are likely to change from one data collection to the next. For this reason, updating the visualization for the current data set, rather than updating the classifier for future processing, may prove more effective. This paper presents an adaptive visualization technique and illustrates the technique with applications several data sets acquired from E-O, thermal, and SONAR imaging systems.

7696A-39, Poster Session

Object-oriented port detection based on meanshift segment

K. Li, Y. Ran, Q. Qin, Wuhan Univ. (China)

An object-oriented method of port target detection is proposed based on the closure feature in this paper. In the study, 1) Mean shift segmentation is implemented. 2) Segment region is judged whether it is water. 3) The center of each land region adjacent sea is computed. 4) Create convex polygon by centers of regions within a certain scale. 5) Recognize port by detecting the inner port waters. Here, waters within the convex polygon are defined as inner port waters.

This method some important features and advantages:

1) Object-oriented technique is used to detect area target of port aimed at reducing the rate of false alarm and this technique gets good results.

2) Considering that closure structure is the most common and more stable structure of port target. In this study, closure feature is used to detect port.

3) It uses the relative position of adjacent regions, and it is insensitive to the rotation of the image, and it is also independent of distortion, position and scale.

4) It is not strict with the accuracy of coastline

At last, this algorithm is applied to remote sensing data acquired from Google Earth, experimental results demonstrates the effectiveness of the algorithm.

7696A-31, Session 8

Evaluating special geometries in curvilinear targets

J. M. Coggins, BAE Systems (United States)

This paper extends my 2008 paper in this conference,"Gauge Features for Curvilinear Target Recogntion", by showing extensions to the basic gauge-coordinate method for handling challenging instances where the basic detection method fails. These include bends (approx. 90-degree turns), terminations, width variances (increased or decreased width of a target), and intersections of 3 or 4 curvilinear targets. Bends are handled by a nonlinear variant of the second derivative operator in which the minimum intensity on the surrounding circle is subtracted from the central blur. Terminations are detected by an interaction between the second-order gauge and the first-order derivative. Width variances are handled by scale change - the trick is in noticing the scale change before the detection fades. Intersections are detected using third- or fourth-order derivatives at slightly larger scales than the component targets.

7696A-32, Session 8

Cascaded automatic target recognition (Cascaded ATR)

B. Walls, Areté Associates (United States)

The global war on terror has plunged US and coalition forces into a battle space requiring the continuous adaptation of tactics and technologies to cope with an elusive enemy. As a result, technologies that enhance the intelligence, surveillance, and reconnaissance (ISR) mission making the warfighter more effective are experiencing increased interest. In this paper we show how a new generation of smart cameras built around foveated sensing makes possible a powerful ISR technique termed Cascaded ATR. Foveated sensing is an innovative optical concept in which a single aperture captures two distinct fields of view. In Cascaded ATR, foveated sensing is used to provide a coarse resolution, persistent surveillance, wide field of view (WFOV) detector to accomplish detection level perception. At the same time within the foveated sensor these detection locations are passed as a cue to a steerable, high fidelity,

narrow field of view (NFOV) detector to perform recognition level perception. Two new ISR mission scenarios, utilizing Cascaded ATR, are proposed.

7696A-33, Session 8

A support vector data description scheme for hyperspectral target detection using first-order Markov modeling

W. A. Sakla, A. K. Chan, J. Ji, Texas A&M Univ. (United States); A. A. Sakla, Univ. of South Alabama (United States)

Spectral variability remains a challenging problem for target detection in hyperspectral imagery. In this paper, we have developed a scheme for performing full-pixel target detection using the kernel-based support vector data description (SVDD). In target detection scenarios, we do not have a collection of samples characterizing the target class; we are typically given a pure target signature that is obtained from a spectral library. In our work, we use the pure target signature and first-order Markov theory to generate N samples to model the spectral variability of the target class. We vary the value of N and observe its effect to determine a value of N that provides acceptable detection performance. In the formulation of the kernel-based SVDD, we have used the radial basis function (RBF) kernel that contains a free parameter s that must be tuned. We have developed an algorithm using an efficient 1-D optimization technique for selecting the kernel parameter s.

We have inserted target signatures into an urban hyperspectral (HS) scene with varying levels of spectral variability to explore the performance of the proposed SVDD target detection scheme in these scenarios. The proposed approach makes no assumptions regarding the underlying distribution of the scene data as do traditional stochastic detectors such as the adaptive matched filter (AMF). Detection results in the form of confusion matrices and receiver-operating-characteristic (ROC) curves demonstrate that the proposed SVDD-based detection scheme is highly accurate and can yield higher true positive rates (TPR) and lower false positive rates (FPR) than the AMF.

7696A-34, Session 8

A decision-level fusion scheme using the support vector data description for target detection in hyperspectral imagery

W. A. Sakla, A. K. Chan, J. Ji, Texas A&M Univ. (United States); A. A. Sakla, Univ. of South Alabama (United States)

In previous work, we have developed a scheme for performing full-pixel target detection using the kernel-based support vector data description (SVDD). The SVDD requires a collection of samples that characterize the class that it aims to model. In target detection scenarios, we do not have a collection of samples characterizing the target class; we are typically given a pure target signature that is obtained from a spectral library. To overcome this problem, we have used a Gaussian model in conjunction with first-order Markov theory to generate samples to describe the spectral variability of the target class using the pure target signature as the mean. However, the Gaussian generated samples also require selection of the variance that dictates the level of variability in the generated target class signatures. Small variance values may prove insufficient for capturing the true spectral variability of the target class; in contrast, large variance values could allow background signatures to be captured by the target SVDD, thus generating undesired false positives.

In this work, we have investigated the use of decision-level fusion techniques for alleviating the problem of choosing a proper variance value. We have utilized decision-level fusion techniques by training a collection of SVDDs with unique variance parameters for each of the target training sets. We have inserted target signatures into both urban and vegetative hyperspectral (HS) scenery with differing levels of spectral variability to explore the performance of the proposed scheme

in these scenarios. Detection results in the form of confusion matrices demonstrate that the proposed SVDD-based decision-level fusion detection scheme is highly accurate and can yield high true positive rates (TPR) and low false positive rates (FPR) using the majority vote (MV) rule for combining labels.

7696A-35, Session 9

A unified approach for database analysis and application to ATR performance metrics

R. B. Johnson, K. Heidary, Alabama A&M Univ. (United States)

An essential component within most approaches used to evaluate ATR algorithm performance is an image database from which are chosen a training set of images. This training set is anticipated to be adequate to allow the ATR algorithm to provide the required level-of-performance throughout the desired domain of effectiveness. Several fundamental questions arise regarding the adequacy of the database to represent the desired domain of effectiveness, the sufficiency of the training set, potentiality of enhancing the constituents of the training set, suitability to determine signal-to-clutter performance, and realism of fairly comparing performance of ATR algorithms to one another. These questions have been addressed through an investigation into a unified approach for database analysis and how it can be applied to evaluating ATR performance metrics. The methodology for this approach provides a deterministic means to examine each object class for adequacy, redundant or excessive data, interference with other object classes, classification margin between object classes, training set sufficiency, and minimum-size training set optimization. By incorporation of anticipated system noise into the database, a statistical determination of the performance ceiling achievable by an idealized matched-filter class ATR algorithm can be made in terms of typically used performance metrics. The performance ceiling sets the boundaries obtainable when the training set and database are used evaluate a typical ATR algorithm. A further means for signal-to-clutter performance evaluation has been developed that generates a series of mutually-uncorrelated clutter images with each having essentially any user-specified peak correlation. Demonstrative examples using this systematic evaluator are provided.

7696A-36, Session 9

Selecting a background for the training images of a correlation filter: a comparative study

A. F. Rodriguez, B. V. K. Vijaya Kumar, Carnegie Mellon Univ. (United States)

Correlation filters (CF) have been widely used for detecting and recognizing patterns in 2D images. These filters are designed to yield sharp correlation peaks for objects of interest while exhibiting low response to clutter and background. CFs are trained with images that resemble the object of interest, however it is not clear what background should be used in these training images. Some methods used a constant zero background while others use the mean of the object of interest over all the images as a constant background. In addition in some designs the images are pre-whitened which alters the DC of each image so that every image has a different background.

A poor background may cause the filter to discriminate based on the background rather than the target pattern. In this paper we compared the effects of different backgrounds on the filter performance in different scenarios under different SNR conditions using both synthetic and real backgrounds. In our comparisons we do not restrict ourselves to using a constant background intensity but also include backgrounds with varying intensity that have a constant mean and a variance equal to the variance of the object of interest. To our knowledge, no such background or comparison has been reported in the CF literature.

7696A-37, Session 9

ARDEC: ARL polarimetric imagery collection experiment

J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States); K. P. Gurton, U.S. Army Research Lab. (United States); D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

The Spectral and Polarimetric Imagery Collection Experiment (SPICE) is a collaborative effort between the Army Armaments Research and Development Engineering Center and the Army Research Laboratory that is focused on the collection of mid-wave and long-wave infrared imagery using hyperspectral, polarimetric, and broadband sensors.

The objective of the program is to collect a comprehensive database of MWIR, LWIR, multispectral LWIR polarimetric, MWIR and LWIR hyperspectral, and 35 and 94GHz Radar over the course of 1 to 2 years to capture performance during a wide variety of weather conditions (fog, rain, snow, etc...) and seasonal changes.

Using the Precision Armament Laboratory tower at Picatinny Arsenal, the sensors will autonomously collect the desired data around the clock at 500 and 1200m ranges. A number of surrogate 2S3 Self-Propelled Howitzer targets will be positioned at different viewing perspectives in an open field. To support the mission, all surrogate targets have been fitted with thermal heating panels to mimic the 2S3 heat profile (engine deck, gun tube, overhead compartment, and wheels) and are instrumented to remotely record target temperatures.

This database will allow for: 1) Evaluation of hyperspectral and polarimetric technologies; 2) Development of new sensors; 3) Understand of signature variability under the different weather conditions; and 4) Evaluation of fusing the different sensor modalities.

In this paper, we will present the SPICE data collection objectives, the ongoing effort, the sensors that are currently deployed, and how this work will assist researches on the development and evaluation of sensors, algorithms, and fusion applications.

7696A-38, Session 9

Impact of stochastic resonance on the probability of classification error of radar targets

I. I. Jouny, Lafayette College (United States)

This study explores the possibility of using stochastic resonance to improve the probability of error of automatic radar target classification systems. These systems rely on sub-optimal hypotheses testing using high resolution range profile features corrupted with noise. The classification problem is essentially a pair-wise comparison between Gaussian Mixtures associated with various target classes. Stochastic resonance has been examined as a tool for improving detection performance of binary hypotheses testing based detectors using the Neyman-Pearson criterion. This work focuses on extending the same idea to multiple hypotheses testing and applying it to radar target recognition. The investigation, which is based on computer simulations and using real radar data, is preliminary but does offer a window into the impact of stochastic resonance on improving the error performance of sub-optimal classifiers.

7696A-72, Session 9

A bio-inspired method and system for visual object-based attention and segmentation

D. Khosla, D. Huber, HRL Labs., LLC (United States)

This paper describes a method and system of human-like attention and object segmentation in visual scenes that (1) attends to regions in a scene in their rank of saliency in the image, (2) extracts the boundary of an attended proto-object based on feature contours, and (3) can be biased to boost the attention paid to specific features in a scene, such as those of a desired target object in static and video imagery. The purpose of the system is to identify regions of a scene of potential importance and extract the region data for processing by an object recognition and classification algorithm. The attention process can be performed in a default, bottom-up manner or a directed, top-down manner which will assign a preference to certain features over others. One can apply this system to any static scene, whether that is a still photograph or imagery captured from video. We employ algorithms that are motivated by findings in neuroscience, psychology, and cognitive science to construct a system that is novel in its modular and stepwise approach to the problems of attention and region extraction, its application of a flooding algorithm to break apart an image into smaller proto-objects based on feature density, and its ability to join smaller regions of similar features into larger proto-objects. This approach allows many complicated operations to be carried out by the system in a very short time, approaching real-time. A researcher can use this system as a robust front-end to a larger system that includes object recognition and scene understanding modules; it is engineered to function over a broad range of situations and can be applied to any scene with minimal tuning from the user.

7696A-73, Session 9

Online recursive estimation of attention and salient regions in visual scenes

D. Khosla, D. Huber, HRL Labs., LLC (United States)

This paper describes an approach for rapidly generating a saliency map and finding interesting regions and in large-sized (i.e., extremely high-resolution) imagery and video. Previous methods of finding salient or interesting regions have a fundamental shortcoming: they need to process the entire image before the saliency map can be outputted and are therefore very slow for large images. Any prior attempts at parallelizing this operation involve computing feature maps on separate processors, but these methods cannot provide a result until the entire image has been processed. Rather than employing a single-step process, our system uses a recursive approach to estimate the saliency, processing parts of the image in sequence and providing an approximate saliency map for these regions immediately. With each new part of the image, a series of normalization factors is updated that connects all image parts analyzed so far. As more of the image parts are analyzed, the saliency map of the previously analyzed parts as well as newly analyzed parts becomes more exact. In the end, an exact global saliency map of the entire image is available. This algorithm can be viewed as (1) a fast, parallelizable version of prior art, and/or (2) a new paradigm for computing saliency in large imagery/video. This is critical, as the analysis of large, high-resolution imagery becomes more commonplace. This system can be employed in a default, bottom-up manner or a directed, top-down manner which will assign a preference to certain features over others. One can apply this system to any static scene, whether that is a still photograph or an image captured from video.

7696A-74, Session 9

A probability of error-constrained sequential decision algorithm for data-rich automatic target recognition

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Because incorrect target classifications on the battlefield can lead to potentially disastrous results, it is critical that all target confusion errors are as rare as possible. Unlike classical fixed-sample hypothesis tests, sequential decision procedures are designed to guarantee that all conditional error probabilities are less than an arbitrary pre-specified level. They do this by occasionally delaying classification until additional observations can be collected. In an environment with pervasive sensing capabilities, sequential procedures represent an attractive formulation for ATR algorithms. Most existing sequential procedures assume that the incremental cost of data collection is high and seek to minimize the total amount of data collected. This assumption is not always consistent with modern sensing capabilities, which can produce massive quantities of data but must make rapid classification decisions and may be limited in terms of available processing capacity. This paper addresses this inconsistency by developing an alternative class of sequential decision procedures that seek instead to reduce the overall processing required to guarantee all pre-specified probabilities of error, without placing explicit constraints on the amount of data collected. The approach explicitly calculates the conditional probabilities of erroneously rejecting each target class, and gradually reduces the number of target hypotheses under consideration as more sensor data are processed. Processing resources are thus proportionally applied to the most likely target classes. The approach is demonstrated on a multi-class ladar-based target recognition problem. Results of the new procedure are compared with classical sequential tests as well as fixed-sample hypothesis tests.

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7696B-40, Session 10

Tracking algorithm selection considerations for airborne laser pointer/tracker system

M. J. Krizo, R. J. Bartell, V. Velten, Air Force Institute of Technology (United States)

The Air Force Institute of Technology's Center for Directed Energy's (AFIT/CDE), under sponsorship of the HEL Joint Technology Office, and as part of a multidisciplinary research initiative on aero optics effects, has designed and fabricated a laser pointing/tracking system. This system will serve as the laser source for a series of in-flight data collection campaigns involving two aircraft.

Real-Time tracking systems have a distinct difference from automatic image analysis. Both activities often involve the segmentation of an image and the automatic location of an item of interest. A number of advanced tracking algorithms have been developed for applications involving processing previously captured data. Medical imaging applications frequently use post processing algorithms to segment anomalies in medical imaging.

In this paper we discuss an airborne laser pointing and tracking system and its requirements, designed and implemented at AFIT. This application is different because the image processing must be completed during the inter-frame period. AFIT analyzed available tracking algorithms including: centroid tracking, Fitts correlator, Posterior Track, and Active Contour. These algorithms were evaluated on their ability to both accurately track and to be computed in real time using existing hardware.

The analysis shows that some of the more accurate tracking algorithms are not easily implementable in real time. Often there are large numbers of correlations that must be computed for each frame. Higher resolution images quickly escalate this problem. Algorithm selection for tracking applications must balance the need for accuracy and computational simplicity.

Real time tracking algorithms are limited by the amount of time between frames with which to processes the data. Specialized hardware can improve this situation. We selected centroid tracking for the airborne application and evaluate its performance to show that it meets design requirements.

7696B-41, Session 10

Evolutionary optimization for tuning nonlinear airborne sightline controllers using an image-based quality metric

D. Anderson, Univ. of Glasgow (United Kingdom)

For long-range imaging or low signal-to-noise ratio environments (e.g. ISTAR - Intelligence, Surveillance Target Acquisition and Reconnaissance operations), sightline jitter is a primary source of image degradation. The conventional figure of merit for assessing the performance of the pointing and stabilisation servos in airborne electro-optic systems is therefore the jitter RMS, with bearing friction often the largest contributor overall. Stabilisation controllers are usually designed to minimise the compliance in each servo axis i.e. transfer function from exogenous disturbance torques to sightline angular deflection. Typically this is achieved by incorporating high-gain integral action in the controller, either by classical PI control or advanced design methods such as H-infinity. However, recent work in this area has shown that pixel smear during camera image integration can be reduced if adaptive friction compensation is used to 'shape' the jitter frequency content in addition to reducing the RMS value. The nonlinear shaping algorithm used here is a modification of an extended Kalman filter torque estimator for friction compensation. This paper presents an extension of this work where the friction compensation

parameters are selected by a genetic algorithm, whose fitness metric comes from a class of image sharpness parameters. Detailed nonlinear simulation of the closed-loop stabilisation axis is used to generate a jitter time response, which is then applied to a baseline image and this dynamic scene passed through a chosen optical train (optical modulation transfer function, imager integration time, special/temporal noise sources etc). Results for several typical scenes are presented.

7696B-42, Session 10

Performance evaluation of an asynchronous two-sensor track fusion algorithm

A. T. Alouani, Tennessee Technological Univ. (United States)

The use of multiple sensors for target tarcking can lead to better quality tracks than when a single sensor is used. For the same number of resources, asynchronous sensors can provide better coverage than synchronous sensors. Recently the authors derived a general purpose fusion algorithm that fuses data from an arbitrary number of asynchronous sensors, where communication delays exist between sensors platform and data fusion center and where data may arrive out of sequence. The objective of this paper is to evaluate the performance of the recently developped asynchronous track fusion algorithm using two asynchronous sensors and simulated target tracks.

7696B-43, Session 10

Design of the coast mode for video tracking systems by the prediction of target occlusion and its on-based implementation

S. Kim, G. Jang, Agency for Defense Development (Korea, Republic of); K. Kwon, Samsung Thales Co., Ltd. (Korea, Republic of)

This paper presents coast mode for electro-optic tracking system to overcome short-term target obscuration. Coast mode, one of tracking modes, is to maintain the servo slew rate with the last known movement parameters. The proposed algorithm makes decision of entering coast mode by the prediction of target occlusion and tries to refind target after the coast time. It composes of 3 steps, the first step is the prediction process of the occlusion by target-like obstacle, the second one is the check process of the occlusion happened after background intensity variation, and the last one is the process of refinding target. The results of computer simulation, test under laboratory and real test with EOTS show the applicability for the automatic video tracking system.

7696B-44, Session 10

Applied optimization of a video pre-processor for tracking

D. A. Scott, O. Mise, GE Fanuc Intelligent Platforms (United Kingdom)

Video tracking systems that are required to track multiple targets must employ robust image processing techniques to ensure that they overcome the dynamic conditions imposed by the environment they operate in. A critical component within a multi-target tracking architecture is the front-end video pre-processor. This component is responsible for maintaining an optimal target-tracking performance through challenging scenarios and background clutter. Following a previous introduction of

an adaptive wavelet-based enhancement pre-processor (AWEP), this paper describes how the inherent scalability of the design allows it to be matched to the specific requirements of various applications. The choice of wavelet kernel and sub-bands is analyzed across a range of application scenarios and structural constraints. A set of comparative results from the tracking system are presented to demonstrate the effectiveness of the AWEP implementation on the tracking performance applied to real video.

7696B-46, Session 10

Unscented particle filter for tracking in three-dimensional space

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Particle Filters can be applied to the estimation problem of nonlinear and non-Gaussian dynamic systems. As it is well known, Particle Filters require the selection of a proposal probability density function (PDF) in order to approximate the posterior PDF. The choice of the proposal PDF is one of the most critical issues in the performance of the algorithm, being the most common strategy to sample from the probabilistic model of the states evolution. The Unscented Particle Filter algorithm consists of a Particle Filter that uses the Unscented Kalman Filter to generate the proposal distribution. In this way, the Particle Filter can incorporate the new observations in the update routine of the algorithm. In this paper we propose the use of the Unscented Particle Filter to track a noisy target in three-dimensional space. The estimation of the panning and vertical tilting angle of the target is performed by measuring the time delays of arrival between microphones. The estimation algorithm is tested by using real recorded data. The results are compared against those obtained by using the Standard Particle Filter. The Unscented Particle Filter responds well to the problem and outperforms the Standard Particle Filter algorithm in most situations.

7696B-47, Session 11

Structural effects and techniques in precision pointing and tracking systems: a tutorial overview

J. M. Hilkert, Alpha-Theta Technologies (United States); D. L. Amil, Raytheon Network Centric Systems (United States)

Structural dynamics is one of the most important elements of a precision gimbal design and often dominates the system line-of-sight stabilization and pointing performance. Structural effects are manifested in these systems in several unrelated ways that members of the design team must understand in order to insure a successful design. Analysis techniques, such as finite elements, and measurement techniques, such as modal analysis, can be used to produce models that accurately predict the various interactions and evaluate either potential or existing designs. However, the successful and efficient application of the above process requires that the underlying principles and effects are well understood by all the members of the engineering design team. This usually includes, as a minimum, the control systems engineer, the structural analyst and the mechanical designer. For example, appropriate transfer functions for the various interactions can be defined and provided by the structural analyst to the control system engineer for evaluation. Often, however, one or more members of the team do not have an appreciation for the effects or the design process required and the result is a frustrated design effort and lower system performance that might have otherwise been readily achieved. While different systems can have vastly different requirements and configurations, the above effects and techniques are common to most and this paper is an attempt to provide a straightforward outline of the more common of these in order to improve communication among design team members so that they can all contribute at their maximum potential.

7696B-48, Session 11

Custom fast steering mirrors for line-of-sight stabilization subsystems

F. E. Morgan, J. J. London, D. P. McIntire, R. E. Owen, Applied Technology Associates (United States)

All acquisition, pointing, and tracking (ATP) systems depend on line-of-sight (LOS) stabilization subsystems to reduce jitter induced on-board the host vehicle. Applied Technology Associates (ATA) has been supporting DoD ATP systems in this area since its inception in 1975, bringing to bear its unique expertise in precision sensing, measurement, and control. Since September 2005, ATA has been developing fast steering mirror (FSM) technology to support LOS stabilization systems. These technology efforts have advanced the state-of-the-art of FSMs in several different areas: (1) high accuracy (better than 10 μrad), (2) low jitter (< 50 nrad), (3) high open-loop bandwidths (over 1 kHz), and (4) high acceleration capability (over 700 rad/sec2). ATA builds and tests FSMs using Silicon Carbide lightweight optics on very rigid aluminum mounts. These FSMs have been controlled by both all-analog controllers and digital controllers. Both optical encoders and differential impedance transducers (DITs) have been used to provide relative position feedback. Significant advances were made by embedding digital mirror control algorithms in a FPGA processing architecture with fabric-based double-precision arithmetic capability. This paper describes the mirrors and the controllers that enable this new level of FSM performance.

7696B-49, Session 11

The design of the pointing control system for the VISSTA ladar testbed

R. R. Fullmer, R. T. Pack, J. A. Swasey, S. E. Budge, Utah State Univ. (United States); T. D. Cook, Naval Air Warfare Ctr. Weapons Div. (United States); N. Maughan, Utah State Univ. (United States)

The VISSTA system is an optical research test-bed developed by the Space Dynamics Laboratory and Utah State University for the U.S. Navy. This system is used to study ladar phenomenology, three-dimensional "texel'® image generation, intelligent scanning methods and to assist in future program development.

VISSTA uses a scanned, single beam pulsed ladar with a range of up to 5 km. The ladar is co-boresighted with a high resolution electro-optical (EO) camera through an optical steering mirror controlled by the Pointing Control Subsystem. The EO camera and the ladar field-of-view consist of a mirror mounted on a two degree-of-freedom Ball-Joint Gimbal with a ±30° circular field-of-regard. The ladar beam is scanned within the EO image using a high-speed 150 mm Fast Steering Mirror. The IR sensor uses a commercial pan-tilt platform. A Litton IMU is used for image stabilization with a Novatel inertial navigation system. A traditional IR camera is included in the design. Either EO or IR images can be used for generating target tracking data from an Octec image processing board.

Operational pointing modes for the controller include direct operator control, ladar image scanning, EO and IR image tracking, large field-of-view mosaic mapping, inertial geolocation and trajectory tracking. The PCS reconfigurable software design is developed using SIMULINK, which is converted into a real-time dynamic library link, which is embedded within the overall LabView instrumentation control software.

This paper discusses the development of line-of-sight ladar pointing algorithms and reports the results of experimental testing.

7696B-50, Session 11

Low-cost inertial estimation unit based on extended Kalman filtering

M. Rezac, Z. Hurak, Czech Technical Univ. in Prague (Czech Republic)

The paper describes some design and implementation aspects of a low-cost inertial estimation unit based on off-the-shelf sensors. The primary task for the unit is to estimate the attitude and position of an unmanned aircraft, but the experience shared in this paper might be of relevance for researchers in other fields. The size of the unit is about the size of a handheld device. It includes a commercially available 3-axis rate gyro combined in a single package with a 3-axis accelerometer, 3-axis magnetometer and a GPS receiver. Barometric pressure sensor is used for the UAV application. All the measured data are fused using the Kalman filtering paradigm. No model of the dynamics of the carrier (aircraft, mobile robot or a patient) is relied upon. The only dynamics is that of sensors, such as the bias inherently present in gyros. Short discussion is dedicated to a proper attitude representation and a motivation for the use of quaternions instead of Euler angles. The choice of extended Kalman filtering methodology was dictated by strong requirements on computational simplicity, but some discussion of other methods is included as well. Some experience with implementation of the proposed scheme on a digital hardware is revealed in the paper. The computational core of the unit is a popular ARM7 based microcontroller. The code was implemented in C using GNU GCC compiler suite. Finally, functionality of the presented device is demonstrated in experiments. Besides simple indoor tests, fly experiments were conducted using a small UAV helicopter.

7696B-51, Session 11

Control design for image tracking with an inertially stabilized airborne camera platform

Z. Hurak, M. Rezac, J. Zoha, Czech Technical Univ. in Prague (Czech Republic)

The paper reports on a few control engineering issues related to design of an image tracking and inertially stabilizing system for an airborne camera platform. The medium-sized platform has been developed by the authors within a joint governmental project with Czech Air Force Research Institute. The platform is based on a common double gimbal configuration with two direct drive motors and off-the-shelf MEMS gyros. Advanced computer vision system is complementing the inertial measurements. Choice of a suitable control configuration is discussed first, because the decoupled structure for the inner inertial rate controllers does not extend easily to the outer visual pointing&tracking loop. It appears that the pointing&tracking controller can benefit much from availability of measurements of an inertial rate of the camera around its optical axis. The proposed pointing&tracking controller relies on feedback linearization well known in image-based visual servoing. Application of a practical observer-based scheme for friction compensation is also described. Simple compensation of a one sample delay introduced into the (slow) visual pointing&tracking loop by the computer vision system is shown. It relies on a simple modification of the well-known Smith predictor scheme where the prediction takes advantage of availability of the (fast and undelayed) inertial rate measurements. Hands-on experience with some of the hardware components used in the project is shared. Finally, first sketch of a dual-stage stabilization system being currently designed as an upgrade to the proposed one (responding to some deficiencies) will be given.

7696B-52, Session 11

Application of nonlinear generalised minimum variance and predictive control to the nadir problem in 2-axis gimbal pointing and stabilization

D. Anderson, P. Savvidis, Univ. of Glasgow (United Kingdom)

Precision tracking applications using two-axis gimbal or antenna actuation systems suffer from a singularity when the inner axis reaches +-90 degrees. This is known by various terms - the keyhole singularity, gimbal lock or the nadir problem. Practically, sightline control is degraded and often lost in a neighbourhood of this singularity due largely to the inability of the outer gimbal servos to track the kinematic rates and accelerations required. The importance of this problem is magnified for systems operating with very low instantaneous field of view, such as laser beamsteering in a directed infra-red countermeasures (DIRCM) engagement. In this paper, two advanced control algorithms are applied to sightline pointing and stabilisation control in the neighbourhood of the nadir. The first approach is a particular application of model predictive control were the predictive controller is used in the track loop to compute future rate demands to the stabilisation loop. The second approach is the nonlinear generalised minimum variance (NGMV) technique. This is a nonlinear control synthesis technique that uses functional analytic methods to deal with arbitrary nonlinearities in the control loop. The performance of both controllers is analysed using a full matlab simulation of the gimbal set and tested in a hardware-in-the-loop environment. The experimental phase was performed in the Glasgow University sightline control laboratory using an Aeromech TigerEye turret.

7696B-53, Session 11

Model for signal acquisition range for laser-guided mortar

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A simple analytical model for the signal acquisition range for a laser guided mortar is presented. The signal consists of a repetitively pulsed 1064 nm laser of fixed pulse duration and a fixed pulse repetition frequency. The pulses are detected by a seeker consisting of a photodiode and a trans-impedance amplifier. Noise is introduced from solar irradiance and from the detector/amplifier electronics. The range can be increased, or alternatively the laser pulse energy can be decreased, by integrating many pulses (processing gain). The model maximizes the acquisition range by optimizing trans-impedance amplifier circuit components.

7696B-54, Session 11

Forming and steering of symmetrical multiple laser beams in optical phased array

J. Zhang, X. Liu, L. Wu, Y. Gan, D. Wang, Harbin Institute of Technology (China)

Multi-beam forming technology is one of the key technologies in phased array optical systems for multi-object treatment and multi-task operation. A multi-beam forming method used in optical phased array was proposed. This method uses isosceles triangle multilevel phase grating to form multiple beams simultaneously. Phase profile of the grating is a quantized isosceles triangle. By changing the phase difference corresponding to the triangle height, multiple beams can be steered symmetrically. It took about 34 ms to calculate a set of parameters for one isosceles triangle multilevel phase grating. With distortion

compensated to 0.0408 , a liquid crystal spatial light modulator was used to test 6 gratings. Each one of them has the same period, which is 16 phase elements, whereas the phase differences corresponding to the triangle height of them are different. Relative diffraction efficiency for multiple beams was greater than 81%, intensity nonuniformity for multiple beams was less than 0.134, and the deflection resolution was 2.263 mrad. Experimental results demonstrate that the proposed method can be used to form and steer symmetrical multiple beams simultaneously with the same intensity and high relative diffraction efficiency in the far field, the deflection resolution is the reciprocal of grating period.

7696B-75, Session 11

Validation of laser ranging with local and global differential GPS

W. Williamson, K. E. Wilson, J. M. Kovalik, M. W. Wright, Y. Barsever, A. Biswas, V. Garkanian, B. Haines, Jet Propulsion Lab. (United States)

As part of a larger effort to develop and validate satellite laser ranging and Differential GPS techniques for centimeter level positioning in space, in the air, and on the ground, this paper reports on a dynamic, ground experiment to validate the accuracy of an optical laser ranging system against differential carrier phase GPS in order to validate both the laser and the methods for processing GPS data. The laser, located at the Jet Propulsion Laboratory Table Mountain Facility and transmitting a 100 Mbps pseudo-random noise data stream, is retro-reflected from a moving truck on an adjacent mountain peak. GPS measurements are collected from two survey-grade, commercial receivers; one antenna located near the laser and the second on the truck. The GPS measurements are processed using the GPS Inferred Positioning Software (GIPSY), which processes data from over 200 ground stations world-wide in order to provide precise GPS satellite clock and orbit locations which enhance position estimation. The laser and GIPSY results are compared with a local differential carrier phase solution using kinematic carrier phase techniques. Results show agreement to centimeter level between the laser and the GPS. The kinematic technique is shown to be more robust to cycle slips, blockage, and phase breaks in the GPS measurements caused by operation in the canyons of the mountain.

Differential global positioning techniques with advanced post processing algorithms can determine relative range between objects to sub-centimeter levels. In deep space communications the Doppler shift in the carrier frequencies is used to determine the range to interplanetary spacecraft to precisions on the order of 1-m. With NASA's resurgent interest in deep space optical communications, future optical communications links to spacecraft will need to support both communications and ranging as radio frequency links on current spacecraft do. We report on the results of a precision aircraft ranging experiment that could support high precision optical transponder type ranging to spacecraft. A100 Mbps pseudo-random noise optical data stream is retro-reflected from an aircraft in flight. The results show that this technique can achieve sub-centimeter ranging precision. The results are compared with high precision differential GPS data simultaneously obtained from GPS receivers on the aircraft and the ground.

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7696C-55, Session 12

Volume holographic MACH correlator

P. M. Birch, A. A. Gardezi, R. C. D. Young, C. R. Chatwin, Univ. of Sussex (United Kingdom)

Volume holographic correlators offer the ability to encode and compare thousands of templates in one operation. Angle multiplexing of each individual template means the position of the correlation spot in the output plane corresponds to the matching template. To be useful as a correlator the shift invariance must be restored by scanning the input image. This can be achieved by implementing the input signal modulation on a high speed SLM such as a MQW or DLP that is capable speeds in excess of 30kHz. The output correlation peak is read out using a high-speed linear CCD camera. The Bragg angle affects the number of templates that can be held on the hologram. However, this is not the same in both directions and this changes the correlator's shift invariance ability in different scan directions. In this paper we investigate this and how it affects the correlators performance.

This arrangement allows thousands of templates to be searched at video rate. The scanning nature allows space domain correlation to be implemented. The system we describe offers the ability to pre-filter the signal. We report on the results of a MACH filter implemented in a volume holographic correlator. The scanning window allows some interesting pre-filtering to be performed, such normalisation and non-linear optimisation.

7696C-56, Session 12

Pattern recognition via multispectral, hyperspectral, and polarization-based imaging

A. El-Saba, M. S. Alam, Univ. of South Alabama (United States)

Pattern recognition deals with the detection and identification of a specific target in an unknown input scene. Target features such as shape, color, surface dynamics, and material characteristics are common attributes used for detection and identification purposes. Pattern recognition using multispectral, hyperspectral, and polarization-based spectral imaging can be effectively exploited to highlight one or more of these attributes for accurate target detection and identification. In general, pattern recognition involves two steps - gathering target information from sensor data, and detect and identify the desired target from sensor data in the presence of noise, clutter and other artifacts. Sensor data fusion is currently being used to effectively recognize and detect one or more of the target attributes. However, an effective solution for accurate target detection involving only a few pixels in the presence of noise, clutter, 3D distortions as well as other artifacts is yet to be found. Targets with spectrally changing attributes require robust pattern recognition algorithms. Consequently, in this paper, we developed an efficient wavelet-filter based fringe-adjusted joint-transform correlation (WFJTC) technique for target detection and identification using multispectral, hyperspectral, and polarization-based passive imaging. The WFJTC has been found to be especially suitable for near real time pattern recognition applications. Test results using various application-specific real life scenarios will be presented to verify the effectiveness of the proposed technique.

7696C-57, Session 12

Correlation filters for activity recognition in video imagery

A. Mahalanobis, S. R. Stanfill, K. Chen, J. Johnson, Lockheed Martin Missiles and Fire Control (United States)

No abstract available

7696C-58, Session 12

Optical security system using multiple phase-shifted reference-based joint transform correlation

M. N. Islam, J. Kostanoski, Farmingdale State College (United States); M. A. Karim, V. K. Asari, Old Dominion Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

A new security system is proposed using optical joint transform correlation technique which employs multiple phase-shifted reference images. In the proposed technique, the address code is used as the reference image and fed into four channels after performing phase shifting on them by different amount. The output signals from each channel are added with the input image to be encrypted for security purpose. Joint power spectra (JPS) signals can then be derived by applying Fourier transform operation, and the resultant signals are phase-shifted and combined to form a modified JPS signal. Inverse Fourier transformation of the modified JPS signal yields the encrypted image which is secure from any unauthorized access and/or loss of information. For decryption, at first the received encrypted image is Fourier transformed and multiplied by the address code used in encryption, which is then inverse Fourier transformed to generate the output signal. The proposed technique does not involve complex mathematical operations on the address code otherwise required in alternate security techniques. This technique requires a simple architecture and yields fast and robust performance with respect to noise and other distortions. Test results obtained using both binary and gray images in noise-free and noisy conditions are presented to verify the performance of the proposed scheme.

7696C-59, Session 13

Real-time intensity filtering with organic photorefractive materials via four-wave mixing

B. Haji-Saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States); N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States); M. Yamamoto, Nitto Denko Technical Corp. (United States); J. Khoury, Air Force Research Lab. (United States)

Recently, three-dimensional video rate image displays have been demonstrated using organic photorefractive materials1. In contrast to nonorganic photorefractive materials, these materials have a large space bandwidth product which allows their use for optical processing in microstructures. In this paper we exploit the nonlinearity inherited in four-wave mixing in organic photorefractive materials and demonstrate edge enhancement, contrast conversion and defect enhancement in a periodical structure. With the availability of these materials having large space bandwidth product, defects enhancement, in particular, has the potential for applications in quality product assurance in periodical structures such as textile fabrics and microelectronics masks.

7696C-60, Session 13

Two-beam coupling image restoration for one-way image transmission in aberrating medium

J. Khoury, B. Haji-Saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States)

In this paper we demonstrate image restoration via photorefractive two-beam coupling. Our restoration is based on coupling between the joint spectra of the distortion impulse response and the distorted image and clean reference beam. The image restoration is used to demonstrate one-way image transmission in an aberrating medium. Our experimental demonstration is supported by theoretical modeling of the restoration process and by computer modeling.

7696C-61, Session 13

Trend adjustment in color images using bi-dimensional empirical mode decomposition

S. M. A. Bhuiyan, J. F. Khan, Tuskegee Univ. (United States); M. S. Alam, Univ. of South Alabama (United States)

Bidimensional empirical mode decomposition (BEMD) decomposes an image into several bidimensional intrinsic mode components, which is useful for various image enhancement and/or feature extraction applications. However, because of the requirement of scattered data interpolation and associated difficulties, the classical BEMD methods appear unsuitable for many applications. Recently, a fast and adaptive BEMD (FABEMD) method is proposed, which alleviates some of the difficulties, otherwise encountered in classical BEMD approaches. On the other hand, existing BEMD methods are proposed for gray scale images only. This paper first presents a novel BEMD approach for color images known as color BEMD (CBEMD), which employs FABEMD principle and decomposes a color image into color bidimensional intrinsic mode components based on hierarchical local spatial variation of image intensity and color. In fact, FABEMD facilitates the extension of the BEMD process for color images in a convenient and useful way, whereas the other interpolation based BEMD techniques appear unsuitable for this purpose. In FABEMD, order statistics filters are employed to estimate the envelope surfaces from the data instead of surface interpolation, which enables fast decomposition and well characterized bidimensional intrinsic mode components. Second, the CBEMD is utilized in this paper for adjusting and/or modifying the color trend of color images. In this process, the image is reconstructed by adding the color bidimensional intrinsic mode components after applying suitably selected weights. Test results with real images demonstrate the potential of the proposed CBEMD method for color image processing, which include color trend adjustment.

7696C-62, Session 14

Implementation of maximum average correlation height (MACH) filter in spatial domain for realistic clutter backgrounds

A. A. Gardezi, Univ. of Sussex (United Kingdom) and COMSATS Institute of Information Technology (Pakistan); P. M. Birch, I. Kyprios, R. C. D. Young, C. R. Chatwin, Univ. of Sussex (United Kingdom)

A moving window is used to implement a Maximum Average Correlation Height (MACH) filter which can be locally modified depending upon its position in the input frame. This enables adaptation of the filter dependant on locally variant background conditions and also enables the normalization of the filter energy levels at each step.

Thus the spatial domain implementation of the MACH filter offers an advantage over its frequency domain implementation as shift invariance is not imposed on it. The only drawback of the spatial domain implementation is the amount of computational resources that are required for its real time implementation.

Recently an optical correlator using a scanning holographic memory has been proposed by Birch et.al.[1] for the real time implementation of space variant filters of this type.

In this paper we describe the discrimination abilities to background clutter, in plane rotation, out of plane rotation and change in scale of a MACH correlation filter implemented in the spatial domain.

[1] Birch, P.M.,Gardezi, A.A., Mitra, B.K., Young, R., Chatwin, C. , "An optical space domain volume holographic correlator." , Proceedings of SPIE [7340-2] , 2009

7696C-63, Session 14

Spectrally invariant synthetic discriminant function for hyperspectral target detection using wavelet-filter joint transform correlation

A. M. El-Saba, A. A. Sakla, Univ. of South Alabama (United States)

We present a novel approach for formulating a spectral synthetic discriminant function (SSDF). As it is known in hyperspectral imagery, the response of the target depends on many factors. One main factor is the dependence of the target response on the selected spectral band. The SSDF is formulated from (L) spectral training images for effective spectrally-invariant target detection. It is shown that the proposed SSDF is effective in applications where the input scene is obtained at different spectral widths than the reference one. Since the SSDF is formulated off line, it does not have any burden on the processing speed of the recognition process.

7696C-64, Session 14

Wavelet-filter joint-transform correlation applied to the recognition of polarization-enhanced subsurface land mine patterns in highly cluttered passive imagery

A. M. El-Saba, S. Alsharif, R. Stripathi, Univ. of South Alabama (United States)

Efficient recognition and clearance of subsurface land mine patterns has been one of the challenging humanitarian and military tasks. Among the several subsurface land mine patterns recognition techniques available, passive imaging techniques are more convenient, safer with good probability of recognition. There exist extensive applications where the joint-transform correlation algorithms have been used for efficient pattern recognition. However, among the several pattern recognition algorithms exist for subsurface land mines, the joint-transform correlation ones has been underrepresented. This paper presents the application of an efficient wavelet-filter joint transform correlation (WFJTC) algorithm for the recognition of passive imagery of subsurface land mines in highly cluttered scenarios. We further show improvements to the recognition efficiency when the WFJTC is applied to passive polarization-enhanced imagery in same scenarios. This improvement is shown using the Receiver Operation Characteristic (ROC) curve approach.

7696C-65, Session 14

Illumination invariant method to detect and track left luggage in public areas

W. Hassan, B. K. Mitra, C. R. Chatwin, R. C. D. Young, P. M. Birch, Univ. of Sussex (United Kingdom)

Surveillance and its security applications have been critical subjects recently with various studies placing a high demand on robust computer vision solutions that can work effectively and efficiently in complex environments without human intervention. In this paper, an efficient illumination invariant template generation and tracking method to identify and track abandoned objects (bags) in public areas is described. Intensity and chromaticity distortion parameters are initially used to generate a binary mask containing all the moving objects in the scene. The binary blobs in the mask are tracked, and those found static through the use of a 'centroid-range' method are segregated. A Laplacian of Gaussian (LoG) filter is then applied to the parts of the current frame and the average background frame, encompassed by the static blobs, to pick up the high frequency components. The total energy is calculated for both the frames, current and background, covered by the detected edge map to ensure that illumination change has not resulted in false segmentation. Finally, the resultant edge-map is registered and tracked through the use of a correlation based matching process. The algorithm has been successfully tested on the iLIDs dataset, results being presented in this paper.

7696C-66, Session 14

People recognition based on clothes characterization

L. Hamoudi, S. Lecoeuche, J. Boonaert, Ecole des Mines de Douai (France)

In contrast with the existing methods, that all rely on recognition of persons' full-body, we propose an automatic person labelling approach for surveillance scenarios, based on the recognition of the top and bottom clothes separately. As pre-processing steps, in each frame, each person is detected and segmented from the background. Each corresponding blob is processed to obtain two sub-blobs respectively related to the top and bottom clothes. Feature vectors containing different color and texture information of these sub-blobs are constructed and exploited to model the corresponding blob appearance. The learning stage is carried out in four steps. First, using a one-class SVM learning scheme, the "margin" of each top clothes, that represents an initial class, is calculated. Then, a confusion matrix is constructed from the overlaps between the margins. Third, initial classes are merged using threshold criteria, forming the final top clothes classes. The same process is applied to obtain the final bottom clothes classes. Finally, a label characterizing the person's clothing is associated to his corresponding top and bottom classes. At the testing step, the top and bottom part of the person are independently classified using a one-class SMV classification scheme, according to the learned classes, and the person is labelled according to his clothes. The system is also able to real time detect when it is new clothes and incorporates them into the decision model. Experiments have been carried out in different rooms and corridors of our laboratory on 60 persons, and high recognition rates have been obtained.

7696C-69, Session 15

Joint transform correlator applied to full-sky star identification

J. Hui, X. Li, J. Yang, J. Yang, Y. Yang, J. Yang, National Univ. of Defense Technology (China)

A rotation-invariant joint transform correlator is proposed for full-sky star identification. Star identification is the basic approach of star tracker used by spacecraft to provide high accuracy attitude. The refresh rate and accuracy of star tracker are constrained as there are a huge number of stars in the sky.

We have developed a novel method for star identification utilizing joint transform correlator (JTC). Star image captured by the camera of star tracker and star map constructed from the catalog are inputted in the JTC, if both input images contain identically the same stars, the correlation image will contain two symmetric correlation peaks and the position of those peaks represents the relative location of the star image, which can be utilized to calculate the current attitude. Rotation-invariant recognition is realized through frequency domain analysis, which avoiding the need to transform data to the polar domain. Refresh rate of this approach is only limited by the rate of SLM, which can achieve 1000~2000 frames per second, and the full-sky identification can be completed in 200ms. As all the stars on the image are used in the correlation, the accuracy and identification rate are improved remarkably. What's more, the noise of detector is not correlated with the stars, as a result, noise can be reduced after the correlation operation. Star image location can be estimated with an accuracy of up to 1/100 pixel. Computer simulations and experiments indicate that this method improves the performance of star tracker remarkably.

7696C-70, Session 15

Accelerated sensor data processing using a multichannel GOC/NN processor

T. Chao, T. Lu, Jet Propulsion Lab. (United States)

No abstract available

7696C-71, Session 15

Optimization of a multi-stage ATR system for small target identification

T. Lu, H. Braun, W. Edens, T. H. Lin, Y. Zhang, W. N. Greene, C. Assad, R. Steele, T. Chao, T. Huntsberger, Jet Propulsion Lab. (United States)

No abstract available

7696C-67, Poster Session

Increase of input dynamic range of optical-digital image correlator using spatially varying pixels exposure technique

S. N. Starikov, M. V. Konnik, Moscow Engineering Physics Institute (Russian Federation)

Registration of correlation signals with linear high dynamic range (HDR) can increase recognition's accuracy and robustness of the optical-digital correlator. The spatially varying pixels exposures (SVE) technique is used for HDR registration of correlation signals formed in quasimonochromatic light; in such case one may consider photo sensor's Bayer colour filters array as an array of attenuating filters. Hence for HDR registration of correlation signals we use the primary colour channel (corresponded to the wavelength of the illumination) as well as other colour channels (accessorial channels). The oversaturated pixels of primary colour channel of a registered image are mapped to linear HDR image utilizing information from accessorial colour channels. The procedure of the HDR images reconstruction using SVE technique is described. Experimental results on obtaining images of correlation signals with linear HDR are presented. The comparison of correlation signals registered with and without application of HDR technique is provided.

7696C-68, Poster Session

Optimum and applications of photorefractive spatial light modulator in optical pattern recognition

X. Li, W. Hu, J. Hui, J. Yang, National Univ. of Defense Technology (China)

With excellent physical properties the photorefractive crystals, such as BSO ($Bi_{12}SiO_{20}$), $BaTiO_3$ and GaAs materials, have, can be widely used in optical correlator to implement auto pattern recognition. As the basic devices in optical correlator, the properties of optically-addressed spatial light modulator are very important. By analyzing the dynamic process of the BSO spatial light modulator, such as the photo-induced current pulses and the fast changes of the read-out light while writing, the distinctness between various operation modes is summarize. Furthermore, the method to optimize the BSO spatial light modulator is proposed. The BSO spatial light modulator working in optimum operation mode is used to design a optical correlator to implement auto pattern recognition. The experiment results indicate that, the optimum operation mode can improve the operation speed and contrast ratio remarkably.

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7697-01, Session 1

Assignment-based multitarget tracking using MIMO radars

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Recently, Multiple-Input Multiple-Output (MIMO) radars have attracted significant attention. The performance of MIMO radars in target detection and localization compared to traditional phased-array and multistatic radars has been extensively dealt with in the literature. However, there is no comprehensive work on the application of MIMO radars in multi target tracking yet.

Assignment based algorithms have been used in the literature to handle data association in a sub-optimal manner. They have been recently applied to multi-target localization using MIMO radars. This algorithm can work efficiently when targets are unobservable in some transmitter-receiver pairs.

In this paper, the assignment method is extended to dynamic multi-target tracking. The problem here is that assignment should be done in two stages. First, possible combinations in all transmitter- receiver pairs have to be found. This can be tackled using the same method applied to multi-target localization. That is, a cost function is defined for each combination using received amplitudes and range bins. An assignment algorithm, then finds a set of combinations minimizing the whole cost. The second step here involves another assignment in time domain where validated combinations in different pairs are associated with each other. In this case, raw data (range bins and amplitudes) of each validated combination are used instead of localization results. Finally, survived tracks of combinations represent hypothesized targets. Given the hypothesized combinations, common filtering approaches are used to find an estimate of tracks for possible targets of interest. The final goal of this paper is to show how manipulating unthresholded data (signals and range bins) may improve tracking performance.

7697-02, Session 1

Integrated clutter estimation and target tracking using spatial, amplitude, and Doppler information

X. Chen, T. Kirubarajan, R. Tharmarasa, McMaster Univ. (Canada); M. Pelletier, ICx Radar Systems (Canada)

In this paper, the problem of tracking multiple targets in unknown clutter background using spatial, amplitude and Doppler measurements is studied. It is common in real tracking problems to have little or no prior information on clutter background. Furthermore, the clutter background may be dynamic and evolve with time. Thus, in order to get accurate tracking results, trackers need to estimate parameters of clutter background in each sampling instant and use these estimates to improve tracking. In this paper, a method that uses position measurements as well as amplitude and Doppler data is proposed to estimate the intensity function of non-homogeneous clutter background. Here, independent identically distributed (i.i.d.) cluster point processes are used to model the distribution of clutter in space, while a stochastic differential equation (SDE) driven by a Wiener process is used to model the amplitude and Doppler of clutter points. The effects of thresholding and detection process are also considered here. Then, the above clutter background estimation method is integrated into the Probability Hypothesis Density (PHD) filter and the Multiple Hypotheses Tracking (MHT) algorithm for target tracking. Through simulations, it is shown that the proposed clutter background estimation method is able to improve the performance of the PHD filter and the MHT tracking algorithm in unknown clutter background.

7697-03, Session 1

Exact nonlinear filters redux

F. E. Daum, A. Noushin, Raytheon Co. (United States)

We derive new exact nonlinear filters by generalizing Daum's theory (1986). Recall that Daum derived an underdetermined system of nonlinear PDEs from the Fokker-Planck equation (as well as the Zakai equation) and the exponential family of unnormalized probability densities, and Daum showed several exact solutions of this system (in certain special cases) by guessing the solution and verifying it. However, one can be more systematic and display all solutions of these PDEs by using the Moore-Penrose inverse. There are only a few currently known classes of filter problems with exact fixed finite dimensional filters, including: Kalman (1960), Benes (1981), Daum (1986, 1987 & 1988), Yau (1997), Wonham (1965), Levine (1986), Wong (1986) & Haussmann (1983). Our work extends this list substantially.

Likewise, Einstein lamented the fact that exact solutions of his gravitational field equations (which is also a system of underdetermined nonlinear PDEs) were very difficult to obtain. However, we now know that there are many distinct solutions that we can compute exactly (see Stephani's book on exact solutions of Einstein's field equations, which uses Lie algebra as the fundamental tool). Yau (one of the world's experts in systems of nonlinear PDEs) has expressed the same opinion about Daum's equations (1998). But substantial progress has been made.

7697-04, Session 1

Generalized particle flow for maximal stability of nonlinear filters

F. E. Daum, A. Noushin, Raytheon Co. (United States)

We derive a new particle flow to maximize the stability of nonlinear filters. This is a generalization of our particle flow induced by log-homotopy, which used the Moore-Penrose inverse to give a unique minimum norm flow. In this paper we compute the most general solution for particle flow, and we compute the free parameters to maximize stability of the nonlinear filter. This greatly improves the performance of such filters for unstable plants, as well as stable plants with slow mixing (due to low process noise and/or eigenvalues that are marginally stable). In particular, particle filters are generally not stable for unstable plants, in contrast with the Kalman filter, which is guaranteed to be stable under very mild conditions (e.g., controllability and observability of the system model), as proven in Kalman's beautiful paper (1963). That is, the Kalman filter is stable despite the instability of the plant model. Recent attempts to understand the lack of stability for particle filters for unstable plants are surveyed by van Handel (SIAM Conference July 2009). This is a very serious practical problem, because the standard plant models for tracking applications are conditionally unstable. Moreover, the estimation accuracy of particle filters is generally a very strong function of the eigenvalues of the plant model. We solve this important practical problem by optimizing the stability of our filter.

The key idea is to compute Bayes' rule using a flow of particles rather than as a pointwise multiplication. This is analogous to the flow of particles used to model the dynamics of the system in standard particle filters. We do not have to use any proposal density or resampling, because we move the particles to the correct distribution in state space using our particle flow. We completely avoid particle collapse or so-called degeneracy.

The differential equation for classic particle flow (Daum & Huang SPIE Conference 2007) was derived using Liouville's criterion, borrowed from physics. Other ingredients include: the chain rule, the Moore-Penrose inverse and a log-homotopy. It turns out that a homotopy does not work at all, owing to the singularity of the resulting ODE, but a log-homotopy

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removes the singularity and works extremely well. The most interesting and challenging part of this filter is the approximation of the gradient of the log-homotopy; we studied 17 distinct methods for this, and we now use a simple but effective approach borrowed from geology, combined with a fast approximate k-NN algorithm. This talk is for normal engineers, who do not have log-homotopy for breakfast.

7697-05, Session 1

A study of 'nonlinear filters with particle flow induced by log-homotopy'

L. Chen, Scientific Systems Co., Inc. (United States)

In this paper, a study of the particle flow filter proposed by Daum and Huang has been conducted. It is discovered that for certain initial conditions, the desired particle flow that brings one particle from a good location in the prior distribution to a good location in the posterior distribution with an equal value does not exist. This explains the phenomenon of outliers experienced by Daum and Huang. Several ways of dealing with the singularity of the gradient have been discussed, including (1) not moving the particles without a flow solution, (2) stopping the flow entirely when it approaches singularity, and (3) stopping for one step and starting in the next. In each case the resulting set of particles are examined, and it is doubtful that they form a valid set of samples for the approximation of the desired posterior distribution. In the case of the last method (stop and go), the particles mostly concentrate on the mode of the desired distribution (but they fail to represent the whole distribution), which may explain the "success" reported in the literature so far. An established method of moving particles, the well known Population Monte Carlo method, is briefly presented in this paper for ease of reference.

7697-06, Session 1

Feynman path integrals and continuous nonlinear filtering

B. Balaji, Defence Research and Development Canada (Canada)

The continuous-discrete filtering problem requires the solution of a partial differential equation termed the Fokker-Planck-Kolmogorov forward equation (FPKfe). Similarly, the continuous-continuous filtering problem requires the solution of the stochastic differential equation called the Duncan-Mortensen-Zakai (DMZ) equation. The reliable solution of these equations is challenging, especially for highly nonlinear filtering problems and in higher dimensions. Furthrmore, their physical meaning is obscure.

In recent published work it has been shown that the continuous filtering problems can be reformulated in terms of Feynman path integrals (FPIs). This approach also leads to an alternative solution of the continuous filtering problems. Specifically, the fundamental solution of the FPKfe can be expressed as an FPI. Furthermore, the fundamental solution for the continuous-continuous filtering problem can also be written in terms of Feynman path integrals, which is independent of the DMZ equation.

The FPI techniques have led to spectacular advances in particle physics and quantum field theory (such as Yang-Mills theories and supersymmetry) and even pure mathematics (topological invariants, Langlands program, etc). A very brief overview of the tremendous impact the FPI has had on theoretical physics and mathematics is presented.

The FPI approach also leads to a an alternative and physical understanding of other aspects of nonlinear filtering. For instance, it leads to the Yau-Yau algorithm for continuous filtering that has been rigorously shown to be equivalent to the robust DMZ equation and to have excellent numerical properties. The FPI results also lead to a generalization of the equivalence of nonlunear filtering and Euclidean quantum mechanics.

7697-07, Session 1

Feynman path integral inspired computational methods for nonlinear filtering

B. Balaji, Defence Research and Development Canada (Canada)

It has been shown that the Feynman path integrals (FPIs) provide an elegant and independent solution to the continuous-discrete and continuous-continuous filtering problems. Apart from offering several conceptual and theoretical insights, the FPI approach is also notable for providing excellent numerical results in otherwise intractable problems, such as lattice computations in quantum chromodynamics (QCD). In this paper, it is shown that even the simplest and crudest approximation of the FPI formula, termed the Dirac-Feynman approximation, leads to a simple and highly accurate solution of several highly nonlinear filtering problems.

The Dirac-Feynman approximation is the simplest and crudest approximation of the FPI that is strictly exact only when the time-step is infinitesimal. However, it is shown that even when the time steps are not infinitesimal but small (as often is the case in practice) the DF approximation is remarkably accurate. The FPI formulas are valid for additive as well as multiplicative noise cases, and for arbitrary discretizations, including the Ito and Stratanovich discretizations.

For a general model the DF approximation states that the fundamental solution is an exponential of a function. The negative of the exponent is termed the action, that is derived from the Lagrangian corresponding state and/or measrement model(s). The terminology alludes to the similarity between nonlinear filtering and quantum and statistical physics.

The DF approximation is used in several examples of highly nonlinear continuous-discrete and continuous-continuous filtering problems. Also discussed are some other path integral inspired algorithms such as Variational Filtering and path integral Monte Carlo algorithms.

7697-08, Session 2

Track-to-track association using a phase-only filter

S. C. Stubberud, Oakridge Technologies (United States); K. Kramer, Univ. of San Diego (United States)

Data association is a key but often overlooked component of the data fusion process chain. The standard kinematic association approach is the chi-squared metric. This technique is a proven report-by-report measure of correlation. In this paper, an alternative approach to association based upon an automated target recognition scheme is analyzed. The technique uses image-processing correlation relying upon the phase-only filter (POF). The POF can compare track-level data over multiple scans simultaneously. The technique requires that the track information be mapped into an image representation, referred to as a tile. The generation of a tile can be based on an amplitude representation of the target track variations. For example, latitude 10 degrees might be a fixed 10x10 image of amplitude (intensity) 10, while latitude 20 degrees could be a fixed 10x10 image of amplitude 55. Alternatively, phase variations, rather than amplitude, could be used to generate the tile. A 10x10 image of a sinusoid with a fixed frequency can have its phase represent the different track element values. These tiles, whether based on amplitude or phase, can represent multiple track attributes over multiple reports.

The capabilities of the POF correlation techniques are compared to the chi-squared metric. Both amplitude and phase tile generation techniques will be applied. The test scenarios will look at formation trajectories, crossing patterns, and maneuvering targets.

7697-09, Session 2

Exploiting multivehicle interactions to improve urban vehicle tracking

R. K. Prasanth, D. Klamer, P. O. Arambel, BAE Systems (United States)

The subject of traffic flow modeling began over fifty years ago when Lighthill and Whitham used flow continuity equation from fluid dynamics to describe traffic behavior. Since then, a multitude of models, broadly classified into macroscopic, mesoscopic and microscopic models, has been developed. Macroscopic models describe the space-time evolution of aggregate quantities such as traffic flow density whereas microscopic models describe behavior of individual drivers/vehicles in the presence of other vehicles. In this paper, we consider tracking of vehicles using a specific microscopic model known as the intelligent driver model (IDM). As in other microscopic models, the IDM equations of motion of a vehicle are nonlinearly coupled to those of neighboring vehicles, with the magnitudes of coupling terms becoming larger as vehicles get closer and smaller as vehicles get farther apart. In our approach, the state of weakly coupled groups of vehicles is represented by separated probability distributions. When the vehicles move closer to each other, the state is represented by a joint probability distribution that takes into account the interaction among vehicles. We use a sum of Gaussians approach to represent the underlying interaction structure for state estimation and reduce computational complexity. In this paper we describe our approach and illustrate the approach with simulated examples.

7697-10, Session 2

Evaluation of performance measures for dynamic objects

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In surveillance and reconnaisance applications, dynamic objects are tracked by tracking filters with sequential measurements. There are two popular implementations of tracking filters: one is the covariance or Kalman filter and the other is the information filter. Evaluation of tracking filters is important in performance optimization not only for tracking filter design but also for resource management. The covariance matrix-based approaches attempt to minimize the covariance matrix-based scalar indexes whereas the information filter-based methods aim at maximizing the information filter-based scalar indexes. Such scalar performance measures include the trace, determinant, norms (1-norm, 2-norm, infinite-norm, and Forbenius norm), and eigenstructure of the covariance matrix or the information matrix and their variants. One natural question to ask is if the scalar performance measures applied to the covariance matrix are equivalent to those applied to the information matrix. In this paper we show most of the scalar performance indexes are equivalent yet some are not. As a result, the indexes if used improperly would provide an "optimized" solution but in the wrong sense. The analysis therefore can serve as a guideline to determine the suitability of performance measures for filter design and resource management.

7697-11, Session 2

Game theoretic sensor management for target tracking

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This paper is to develop and evaluate a game-theoretic approach to distributed sensors management via competition and learning. We will extend our previous work published in 2009 SPIE Conference on Signal Processing, Sensor Fusion, and Target Recognition from the following aspects: 1) Including more realistic sensor model such as GMTI and UGS; 2) Considering more factors in the utility function such as target importance, etc; 3) integrating the game-theoretic sensor manager with the target state estimator. Monte Carlo Simulation results demonstrate the feasibility of the proposed game theoretic sensor management approach.

7697-12, Session 2

Image-based tracking and sensor resource management for UAV's in an urban environment

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Coordination and deployment of multiple unmanned air vehicles (UAVs) requires a lot of human resources in order to carry out a successful mission. The complexity of such a surveillance mission is significantly increased in the case of an urban environment where high rise buildings and complex road networks make the coordination and target tracking tasks extremely difficult. In the proposed architecture, we focus on the control and coordination of multiple UAVs with video sensor for tracking multiple targets. The emphasis is on collision avoidance, prioritization of the targets, persistent target tracking, and UAV mission re-assignments. The command center is responsible for target prioritization and autonomous control of multiple UAVs, enabling a single operator to monitor and control a team of UAVs from a remote location. The results are demonstrated using extensive 3D simulations in Google Earth high fidelity environment.

7697-13, Session 3

PHD filtering in known, target-dependent clutter

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The conventional PHD filter presumes the existence of an a priori Poisson false alarm/clutter model. This model consists of two parts: the spatial distribution of the false alarms/clutter, and the expected number of false alarms. This model implicitly presumes that clutter is solely an artifact of the sensor. In many cases, however, clutter can depend on the states of the targets. One example is electronic counter-measure (ECM) spoofing, in which aircraft receive and then retransmit radar pulses, creating false targets on the radar screen. This paper generalizes the PHD filter to the case of target-dependent clutter. It is assumed that a distinct a priori Poisson clutter process is associated with each target. Multitarget calculus techniques are used to derive formulas for the measurement-update step. These formulas require combinatorial sums over all partitions of the current measurement-set. Further research is required to address the resulting computational issues.

7697-14, Session 3

CPHD filtering with unknown probability of detection

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

The conventional PHD and CPHD filters presume that the probability pD(x) that a measurement will be collected from a target with state-vector x (the state-dependent probability of detection) is known a priori. However, in many applications this presumption is false. A few methods have been devised for estimating the probability of detection, but they typically presume that it is constant in time and in the region of the target.

This paper introduces a CPHD filter that is capable of multitarget track-before-detection operation even when probability of detection is not known and is not necessarily constant, either temporally or spatially. (A corresponding PHD filter can be derived, but is guaranteed to have poor performance.) Furthermore, these filters are potentially computationally tractable. I begin by deriving CPHD/PHD filter equations for the case when probability of detection is unknown but the clutter model is known a priori. Then, building on the results of a companion paper, I derive a CPHD filter for the case when neither probability of detection or the background clutter are known.

7697-15, Session 3

Tracking large number of targets with the zero-false-alarm CPHD filter

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This article presents a special case of the Cardinalized Probability Hypothesis Density (CPHD) filter capable of simultaneously tracking a large number of closely spaced targets under zero false alarm (ZFA) conditions. While the CPHD filter is well-suited for tracking closely spaced targets, its high complexity, which is usually quoted as being cubic but with careful execution can actually be reduced to quadratic in the number of measurements, hinders its application to problems with very large number of targets. In this work we show that the special case of the CPHD filter under ZFA conditions is linear in the number of measurements and is subsequently capable of tracking thousands of targets simultaneously. Numerical studies using Gaussian mixture implementation demonstrate that this so-called ZFA-CPHD filter can simultaneously track up to 1500 targets with different birth and death times, on a standard laptop computer.

7697-16, Session 3

Robust distributed data fusion of multi-object probability hypothesis densities

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Covariance Intersection has proved to be a very powerful and general method for fusing data in arbitrary networks and has been used in a range of distributed and other applications where full correlation structures cannot be maintained. However, CI only utilizes the mean and covariance of the estimates and cannot exploit any additional distribution information such as the number of modes. The generalization of CI to multi-object posteriors was proposed by Mahler specifically to extend Finite Set Statistics (FISST) to suboptimal distributed environments, and this generalisation has proved to be extremely valuable for distributed estimation in the single-target case. However, due to the inherent complexity of multi-object posteriors, no authors have attempted to apply these equations in their original multi-object form. We derive tractable approximations of the fused multi-object distributions by deriving their first-order moment or Probability Hypothesis Density (PHD) based on the assumption of Poisson and IID cluster posteriors, as used in the PHD and CPHD filters.

7697-17, Session 4

Probability hypothesis density filters for multigroup multitarget tracking

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A group target can be viewed as a collection of individual targets with some common dynamic and observation characteristics. The problem of multi-group multi-target tracking requires the estimation of the correct number of groups and their constituent members from a sequence of observation sets. Mahler proposed a solution to the multi-group multi-target tracking problem through an extension of the multi-object Bayes filter to multiple groups of targets using Finite Set Statistics and Neyman-Scott cluster processes. We derive explicit forms for the first-order approximation, known as the intensity function or Probability Hypothesis Density, of multi-group multi-object Bayes filters using general cluster processes from point process theory. This can also be viewed as a Bayes-optimal solution to the problem of dynamic clustering.

7697-18, Session 4

Multitarget passive acoustic tracking: an application of random finite set data fusion

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Passive acoustic tracking benefits animal bio-behavioral study in replacing or enhancing human involvement in performing field data collection. Multiple simultaneous vocalizations are a common occurrence in a forest or a jungle, where many species are encountered. Given a set of nodes that are capable of producing multiple direction-of-arrivals (DOAs) estimates, such data needs to be combined into meaningful tracks. Random Finite Set theory provides the mathematical probabilistic model, which is suitable for analysis and optimal fusion center synthesis. Our proposed algorithm will be tested, modified (incorporating conceptual reformulations), and retested based on real life experimentally collected data.

7697-19, Session 4

Situational awareness sensor management of space-based EO/IR and airborne GMTI radar for road targets tracking

A. I. El-Fallah, A. Zatezalo, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); R. K. Mehra, Scientific Systems Co., Inc. (United States)

Dynamic sensor management of heterogeneous and distributed sensors presents a daunting theoretical and practical challenge.

We present a Situational Awareness Sensor Management (SA-SM) algorithm for the tracking of ground targets moving on a road map.

It is based on the previously developed information-theoretic Posterior Expected Number of Targets of Interest (PENTI) objective function, and utilizes combined measurements form an airborne GMTI radar, and a space-based EO/IR sensor.

The resulting filtering methods and techniques are tested and evaluated. Different scan rates for the GMTI radar and the EO/IR sensor are evaluated and compared.

7697-20, Session 4

EO/IR satellite constellations for the early detection and tracking of collision events

A. Zatezalo, A. I. El-Fallah, Scientific Systems Co., Inc. (United States); R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States); R. K. Mehra, Scientific Systems Co., Inc. (United States)

The detection and tracking of collision events involving existing Low Earth Orbit (LEO) Resident Space Objects (RSOs) is becoming increasingly important with the higher LEO space objects traffic volume which is anticipated to increase even further in the near future.

Changes in velocity that can lead to a collision are hard to detect early on time, and before the collision happens.

Several collision events can happen at the same time and continuous monitoring of the LEO orbit is necessary in order to determine and implement collision avoidance strategies. We present a simulation of a constellation system consisting of multiple platforms carrying EO/IR sensors for the detection of such collisions.

The presented simulation encompasses the full complexity of LEO trajectories changes which can collide with currently operating satellites.

Efficient multitarget filter with information-theoretic multisensor management is implemented and evaluated on different constellations.

7697-21, Session 4

Receding horizon controller using particle swarm optimization for closed-loop space surveillance and satellite tracking

This paper presents a centralized receding discrete time horizon controller (RHC) for scheduling the tasks (observations) of a heterogeneous ensemble of space observing sensors. The controller operates in a closed feedback loop with a Bayesian Multiple Hypothesis Tracker (MHT) that fuses the disparate sensor data to produce target declarations and state estimates. The reward function is based on expected Fisher information gain and priority scaling of satellite tracks and space surveillance regions. A customized Particle Swarm Optimizer (PSO) is developed to handle the resulting non-Markovian, time-varying, multi-modal, and discontinuous reward function. The algorithms were evaluated by simulating space surveillance scenarios using idealized optical and radar sensors, satellite two-line element (TLE) sets from the US Space Track catalog, and relevant factors such as illumination and intervisibility. Simulation results show improved aggregate target detection, track accuracy, and track maintenance for closed loop operation as compared with typical open-loop surveillance plans.

7697-22, Session 6

Constraint optimized weight adaptation for Gaussian mixture reduction

Gaussian mixture reduction is traditionally conducted by recursively selecting two components that appear to be most similar to each other, and merging them. Different definitions on similarity measure have been used in literature. For the case of one-dimensional Gaussian mixtures, K-means algorithms and some variations are recently proposed to cluster Gaussian mixture components in groups, use a center component to represent all in each group, readjust parameters in the center components, and finally perform weight optimization. In this paper, we focus on multi-dimensional Gaussian mixture models. With a variety of reduction algorithms and possible combinations, we developed a hybrid algorithm with constraint optimized weight adaptation to minimize the integrated squared error (ISE). In additions, with computer simulations, we showed that the proposed algorithm provides an efficient and effective Gaussian mixture reduction performance in various random scenarios.

7697-23, Session 6

A comparison of distance metrics between mixture distributions

Many applications such as content-based image retrieval (CBIR) and audio retrieval require measuring the distance between mixture types of distributions. There are various techniques to serve this purpose. This paper compares some of these techniques by integrating several distance metrics with a novel distance measure for probability distribution of mixture type. We apply several metrics such as Integrated Squared Error distance, the Bhattacharyya distance and the Kullback Leibler distance to measure distance between Gaussian mixture distributions. We compare their performances based on precision rate and false positive rate with a wide variety of simulated data.

7697-24, Session 6

Convergence analysis of parallel genetic algorithm based on allied strategy

Premature convergence has been a main problem in Genetic Algorithms (GAs). In order to prevent premature convergence, we introduce an allied strategy with human in the loop, and present a parallel genetic algorithm based on the allied strategy (PGAAS). The PGAAS can prevent premature convergence, increase the optimization speed, and has been successfully applied in a few systems. In the paper, we first present the Markov chain model in the PGAAS. Based on this model, we analyze the convergence property of PGAAS. We then present the proof of global convergence for the PGAAS algorithm. Finally, we discuss several potential applications with the proposed methodology.

7697-25, Session 6

A random neural network approach to an assets to tasks assignment problem

We investigate the assignment of assets to tasks where each asset can potentially execute any of the tasks, but assets execute tasks with a probabilistic outcome of success. There is a cost associated with each possible assignment of an asset to a task, and if a task is not executed there is also a cost associated with the non-execution of the task. Thus any assignment of assets to tasks will result in an expected overall cost which we wish to minimise. We formulate the allocation of assets to tasks in order to minimise this expected cost, as a nonlinear optimisation problem. A neural network approach for its approximate solution is proposed based on selecting parameters of a Random Neural Network (RNN), solving the network in equilibrium, and then identifying the assignment by selecting the neuron whose probability of being active is highest.

Evaluations of the proposed approach are conducted by comparison with the optimum (enumerative) solution over a large number of randomly generated test cases. The evaluation indicates that the proposed RNN based algorithm comes at most within 10% of the cost obtained by the optimal solution in all cases. The RNN based approach is fast and is of low polynomial complexity in the size of the problem.

7697-26, Session 6

An information theoretic approach for performance evaluation of multi-class assignment systems

R. S. Holt, P. Mastromarino, E. Kao, M. Hurley, Lincoln Lab. (United States)

Multi-class assignment is often used to aid in the exploitation of data in the Intelligence, Surveillance, and Reconnaissance (ISR) community. For example, tracking systems collect detections into tracks and recognition systems classify objects into various categories. The reliability of these systems is highly contingent upon the correctness of the assignments. Conventional methods and metrics for evaluating assignment correctness only convey partial information about the system performance and are usually tied to the specific type of system being evaluated. Recently, information theory has been successfully applied to the tracking problem in order to develop an overall performance evaluation metric. In this paper, the information-theoretic framework is extended to measure the overall performance of any multi-class assignment system, specifically, any system that can be described using a confusion matrix. The performance is evaluated based upon the amount of truth information captured and the amount of false information reported by the system. The information content is quantified through conditional entropy and mutual information computations using numerical estimates of the association probabilities. The end result is analogous to the Receiver Operating Characteristic (ROC) curve used in signal detection theory. This paper compares these information quality metrics to existing metrics and demonstrates how to apply these metrics to evaluate the performance of a recognition system.

7697-27, Session 6

Direct message passing for hybrid Bayesian networks

K. Chang, W. Sun, George Mason Univ. (United States)

Probabilistic inference for hybrid Bayesian networks, in which both discrete and continuous random variables are involved, has become an important research topic recently. This is mainly due to the practical needs in many real world applications where both discrete and continuous variables are necessary. In this paper, we present a message passing framework called Direct Message Passing (DMP) that allows message exchanges directly between discrete and continuous variables. In the framework, we use Gaussian mixtures to represent messages for continuous variables and derive formulae to compute messages for various dependence relationship. While the DMP algorithm can only provide approximate solution for general network structure, it is scalable in the sense that it only requires a fixed number of message passing before converging to a solution and the number of Gaussian components in the mixture model can be reduced according to a predefined error bound. The simulation results validate the effectiveness of the newly proposed methodology.

7697-28, Session 7

Confidence of a ROC manifold

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A Classification system such as an Automatic Target Recognition (ATR) system with N possible output labels (or decisions) will have N(N-1)

possible errors. The Receiver Operating Characteristic (ROC) manifold was created to quantify all of these errors. Truthed data will produce an approximation to a ROC manifold. How well does the approximate ROC manifold approximate the TRUE ROC manifold? Several metrics exist that quantify the approximation ability, but researchers really wish to quantify the confidence in the approximate ROC manifold. This paper will review different confidence definitions for ROC curves and will derive an expression for confidence of a ROC manifold. The foundation of the confidence expression is based upon the Chebyshev inequality. Examples will be given that demonstrate how the confidence expression is computed for a given ROC manifold.

7697-30, Session 7

Data-driven modeling of nano-nose gas sensor arrays

T. S. Alstroem, J. Larsen, C. H. Nielsen, N. B. Larsen, Technical Univ. of Denmark (Denmark)

We present a data-driven approach to classification of Quartz Crystal Microbalance (QCM) sensor data. The sensor is a nano-nose gas sensor that detects concentrations of analytes down to ppm levels using innovative plasma polymorized coatings. Each sensor experiment takes approximately one hour hence the number of available training data is limited. We suggest a data-driven classification model which work from few examples. The paper compares a number of data-driven classification and quantification schemes able to detect the gas and the concentration level. The data-driven approaches are based on state-of-the-art machine learning methods and the Bayesian learning paradigm.

7697-31, Session 7

A linear stochastic process and a genetic algorithm for ship trajectory modeling

M. Hadzagic, H. Michalska, McGill Univ. (Canada)

In maritime surveillance, data obtained from various information sources usually differ to a great extent in their temporal resolution. This makes the contact report data usually available for batch processing. Additionally, the dissimilar multi-source information environment results in contact report data characterized by different uncertainties, the so-called heteroscedastic measurements.

The Integrated Ornstein-Uhlenbeck (IOU) process in conjunction with Kalman filtering (KF) is known to be used in certain maritime surveillance applications, such as tracking submarines and surface ships [1]. In the open literature, the first implementation, application, and the accuracy and functionality assessment of the IOU process used for ship motion modeling was previously reported in [2]. In [3], a combination of genetic, simulated annealing, and chemotaxis algorithm, employing the so-called track templates capable to incorporate non-sensor information, is used to produce ship tracks models. However, the last method does not completely account for heteroscedatic measurement errors.

The goal of the present paper is to compare the performance of the method described in [2] and the method that employs a basic genetic algorithm in the presence of positional heteroscedastic measurements, which are assumed to be received at irregular time intervals, yet processed in batches. Such a study has never been reported. The quality of the produced tracks is assessed using several simulated scenarios and evaluated statistically. The results of this performance evaluation are useful as they facilitate selecting the appropriate approach to data processing in maritime surveillance applications, hence contribute to increased maritime domain awareness.

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7697-32, Session 8

Optical- and IR-sensor fusion for moving object segmentation by using optical flow

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In this paper we address the problem of segmenting moving objects in image sequences, which are recorded in highly complex and uncontrollable environments. An image sequence (for instance provided by an optical sensor) is a much richer source of information than a still image, mainly because of the capture of motion. Nevertheless, due to the wide range of sensing environments, information from a single sensor may often be insufficient for a complete description of the phenomena under observation. Information provided by imaging sensors of various modalities may then be combined, to give a more complete image of the scene under observation for more robust object segmentation.

We propose a segmentation strategy which is accomplished by estimating the motion field in each individual image sequence by use of a combination of gradient- and correlation-based techniques. We then propose a set of belief functions over the optical flow field for evaluation of the evidence of foreground objects. The individual evidence functions are then combined by use of a weighted sum of conjunctive and disjunctive combination rules. Moreover, with the aim of accounting for the reliability of sources, we utilize a class of robust combination rules (RCR) in which the weights are a function of the conflict between two pieces of information.

A complete description of the proposed methods is presented. Furthermore, we investigate sequences of a real world scenario recorded by a static array of sensors where the array consists of an optical sensor and an IR-sensor, which are both aligned in time and space. Results regarding these sequences are presented.

7697-33, Session 8

An indoor WSN-based localization platform using XBee radios and Arduino microcontrollers, incorporating three different localization techniques and an optimal fusion rule

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In the last years RF-based indoor localization is being thoroughly investigated, since there is not yet an industry standard for accurate indoor localization and location based services (like the GPS for outdoor). Direction-of-Arrival (DoA), Time-of-Arrival (ToA), Received-Signal Strenth (RSS) and Ultra Wideband (UWB) techniques have been applied for indoor localization in recent literature, and techniques for accuracy improvement have been proposed [1-2]. Research findings indicate that RSS-based techniques are most easily deployed, since RSS-measuring equipment is widely available, and can be easily combined with existing or co-deployed communications infrastructure.

In this paper, we develop a Wireless Sensor Network based on XBee radios and Arduino microcontrollers, aiming in providing a platform capable of sensing the environment, localizing users and serve as a means of wireless communications at the same time. In order to compare

various techniques and achieve superior localization accuracy, we have investigated three different RSS-based techniques, namely plain RSS measurements, scene-analysis based on fingerprinting, and range-free localization. Furthermore, a fusion method is proposed, incorporating an optimal fusion rule based on these three underlying techniques, in order to achieve higher accuracy. Experimental results illustrate the performance of each technique as well as the fused performance of various combinations among them. The proposed platform achieves satisfactory performance results and may be used in emergency indoor applications, like firefighting, ambient assisted living etc.

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7697-34, Session 8

Framework for data fusion of biometric data from seismic and micro-Doppler active ultrasonic sensors for robust subject identification

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Proposed herein is a framework between disparate multiple sensing modalities with correlated biometrics between the orthogonal modalities to aide in actor identification and discrimination within a particular defined scene. For the purposes of detection and classification, there are advantages and disadvantages to using either seismic or ultrasonic-sensing modalities individually to successfully detect, identify, and classify a subject to some degree. The seismic modality provides a clean; separable set of results for walkers close to the sensor, but in general fails to be as successful at a larger stand-off due to ground wave attenuation providing some level of detection but little refinement. The ultra-sonic modality provides stronger detection results from a greater stand-off distance in direct comparison to the seismic sensor due to higher fidelity of the signal. However, the resulting signature is harder to separate into individual walk-cycle events due to the broadband nature of the ultrasonic profile. In light of the advantages and disadvantages, it is desirable to utilize the capabilities of both sensors, to create a framework harmonious singular solution providing a robust solution for detection, identification, and classification of the actor within the scene. Data Fusion techniques in this particular case Hidden Markov Models and Dempster Shafer Theory provide a framework and methodology for exploiting each modality in an optimized and complementary fashion. In a probabilistic sense, this means that the chance of a successful detection is increased through a decision model that uses both the seismic and ultrasonic detection results to intelligently detect a target.

7697-35, Session 8

True-color EMCCD/microbolometer-fused night vision camera

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A fully functional prototype night vision camera system is described which produces true-color fused visible/near-infrared (VNIR) and thermal long-wave infrared (LWIR) imagery. True color information is obtained using a low-light-level color EMCCD camera with a mosaic filter pattern. The output from this VNIR camera is combined with the output from an LWIR microbolometer camera in a manner that displays the complimentary information from both sources without destroying the

true-color information. True-color information has been proven to improve scene understanding, object detection, and reduce viewer fatigue. In addition, it greatly assists in identification and tracking of people (e.g., specific colored clothing) and vehicles (e.g., specific colored paint). The system can obtain true-color information in day-light down to about ¼-moon conditions, below this light level the system can function in a monochrome fusion mode down to clear starlight conditions, and in even darker conditions the system can revert to a thermal-only mode. An embedded processor is used to perform the fusion in real-time at 30 frames/second and conducts the following tasks during each frame period: (a) warps one image to match the field of view, orientation, and optical axis of the other image; (b) extracts color information from the VNIR image; (c) runs an edge detection filter on the LWIR image; and (d) fuses the VNIR, LWIR, and LWIR edge images with adjustable weightings. The processor outputs fused imagery in two forms: (1) digital 24-bit RGB or YUV data via CameraLink with a pixel resolution of 640x480 and (2) NTSC color analog.

7697-36, Session 8

An extended KALMAN arithmetic for Pan&Tilt system's attitude estimation

Z. Gong, T. Gao, J. Rao, J. Luo, X. Gao, Shanghai Univ. (China)

The attitude estimation of Pan&Tilt system for the small unmanned aerial vehile(SUAV) was gotten by a new extended Kalman arithmetic. In order to improve the availble payload of SUAV, The MEMS sensors are selected to design the sensor system.the MEMS sensors included accelerometer,angluar rate gyroscope and magnetometer .Firstly, the hardware system of sensor system was designed. Secondely,the translation among three kinds of orientation expression were described. The orientation expression included Euler angle, quaternion and a 3x3 rotation matrix. Thirdly,the model of threel MEMS sensors were set up and were analysed about error reasons.Furthermore, the magnetometer was compensated with environment disturb magnetic field by the data analysis. Then a new KALMAN arithmetic model was put forward basing on analyzing sevaral kinds of MEMS sensors.The state vector was the seven-dimesional vector which was made up of the four-dimesional quaternion and four-dimesional angular rate error. The observation vector was the three Eular angles.In the same time,the sate matrix and observation matrix were gotten. In order to implemthe arithmetic on the microprocessor,the extended KALMAN was gotten through linearizing and discreting above new KALMAN filter arithmetic.Finally, to testify the above attitude sensors system,a experiment in static and dynamic states was carried out by comparing with other high precision sensor system. Average error and mean square error prove that the snesor system has good performace and satisfies the requirement of the Pan&Tilt system for SUAV.

7697-55, Poster Session

A generalized evidence conflict measure

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Dempster-Shafer Theory is a general framework for reasoning with uncertainty and has a wide range of applications in information fusion. Dempster's rule is the conventional evidence combination rule. Although it possesses many interesting mathematical properties, such as associativity and commutativity, Dempster's rule has suffered much criticism because it produces counter-intuitive results when the conflict between pieces of evidence is very high. In order to solve the defects of Dempster's rule, many modified rules have been proposed . These modified rules are all based on the reallocation of conflicting mass defined by Shafer.

To handle the conflicts among pieces of evidence properly, the premise is to define a proper conflict measure. Shafer's conflicting mass is the sum of products of incompatible basic belief assignments between beliefs. It can be used as a measure of conflicts between beliefs and easily

generalized for more than two beliefs. Jousselme treated the basic belief assignment (BBA) as the coordinates of a point in the geometrical space and proposed the principled distance between two BBAs to quantify their inconsistency, but did not consider the conflicting mass. Any measure based on the distance between two BBAs cannot be directly generalized for more than two beliefs. Liu Wei-ru defined a two-dimensional measure to quantify the conflict between two combined beliefs. It considers the conflicting mass and the distance between BBAs simultaneously. It is more comprehensive than the other two measures, but needs to determine a coefficient that is entirely subjective. Because the second element of Liu's two-dimensional measure is a distance measure, it has all the defects of distance-based conflict measure.

The above conflict measures do not consider the potential conflict, which cannot be neglected in many cases. After analyzing the potential conflict that was proposed qualitatively by Milan Daniel, this paper first defines the local potential conflict quantitatively. The local conflicting mass is the special case of local potential conflict. Then the concept of generalized evidence conflict is proposed. The generalized evidence conflict is the sum of the local potential conflicts and conflicting masses. The generalized evidence conflict is more comprehensive and can measure the conflicts among more than two pieces of evidence. When there is no potential conflict, it becomes the same as Shafer's conflicting mass. Several numerical examples and simulations demonstrate this measure's rationality.

7697-37, Session 9

BiTS: a biologically inspired target screener for detecting manmade objects in natural clutter backgrounds

M. J. Carlotto, General Dynamics Advanced Information Systems (United States)

Motivated by biologically-inspired architectures for video analysis and object recognition, a new single band electro-optical (EO) object detector is described for aerial reconnaissance and surveillance applications. Our bio-inspired target screener (BiTS) uses a bank of Gabor filters to compute a vector of texture features over a range of scales and orientations. The filters are designed to exploit the spatial anisotropy of manmade objects relative to the background. The background, which is assumed to be predominantly natural clutter, is modeled by its global mean and covariance. The Mahalanobis distance measures deviations from the background model on a pixel-by-pixel basis. Possible manmade objects occur at peaks in the distance image. We measured the performance of BiTS on a set of 100 ground-truthed images taken under different operating conditions (resolution, sensor geometry, object spacings, background clutter, etc.) and found its probability of detection (PD) was 12% higher than a RX anomaly detector, with half the number of false alarms at a PD of 80%..

7697-38, Session 9

IDC: a system for automatically detecting and classifying manmade objects in overhead imagery

M. J. Carlotto, General Dynamics Advanced Information Systems (United States)

The automatic detection and classification of manmade objects in overhead imagery is key to generating geospatial intelligence (GEOINT) from today's high space-time bandwidth sensors in a timely manner. A flexible multi-stage object detection and classification capability known as the IMINT Data Conditioner (IDC) has been developed that can exploit different kinds of imagery using a mission-specific processing chain. A front-end data reader/tiler converts standard imagery products into a set of tiles for processing, which facilitates parallel processing on multiprocessor/multithreaded systems. The first stage of processing

contains a suite of object detectors designed to exploit different sensor modalities that locate and chip out candidate object regions. The second processing stage segments object regions, estimates their length, width, and pose, and determines their geographic location. The third stage classifies detections into one of K predetermined object classes (specified in a models file) plus clutter. Detections are scored based on their salience, size/shape, and spatial-spectral properties. Detection reports can be output in a number of popular formats including flat files, HTML web pages, and KML files for display in Google Maps or Google Earth. Several examples illustrating the operation and performance of the IDC on Quickbird, GeoEye, and DCS SAR imagery are presented.

7697-39, Session 9

Robust multiscale multimodal image registration

M. Holtzman Gazit, I. Yavneh, Technion-Israel Institute of Technology (Israel)

Multi modal image registration is a process aimed at aligning two or more images of the same scene acquired by different devices, possibly at different times. It is especially difficult when one of the images contains only a small region of the other image. With no prior knowledge, there is a need to search for the alignment parameters over the entire image. If an associated local optimization scheme is initialized far from the global solution, it usually converges to a local optimum. Our method presents a multi-scale approach that greatly enlarges the basin of attraction of the global optimum, and demonstrates how to find the correct solution to the optimization problem efficiently and reliably. We construct a hierarchy of images with varying levels of detail while maintaining the important features of the image. Next, we find a solution which is a consensus for all levels. This way we allow a fast and reliable image alignment. The method, which consists of two types of coarsening, successfully removes the vast majority of the local minima without losing the global optimum, and therefore is able to find the correct solution to the optimization problem efficiently and robustly, solving a relatively small number of local optimization problems, and tracking a small number of likely candidates. Multi-modal registration is required in many types of applications, including medical imaging, remote sensing and defense and security algorithms such as target detection, airborne intelligence and others.

7697-40, Session 9

3D exploitation of large urban photo archives

P. L. Cho, Lincoln Lab. (United States); N. Snavely, Cornell Univ. (United States); R. Anderson, Lincoln Lab. (United States)

Millions of photos shot by inexpensive digital cameras in cities can now be accessed via the web. But usually no connection exists between retrieved urban thumbnails other than their having been collected in a common metropolitan area. Some organizing principle is therefore needed to enable intuitive navigating and efficient searching of vast imagery archives. Fortunately, three-dimensional geometry provides such an organizing principle for images collected at different times, places and resolutions. In this talk, we present a 3D approach to exploiting 2D urban imagery.

We work with over 1000 digital photos shot of the lower Manhattan skyline and the Statue of Liberty downloaded from www.flickr.com. Aside from being tagged as related to New York City, such uncooperatively collected imagery is unorganized. But a machine can take advantage of multiple views of static urban objects to recover relative 3D locations of the photos' cameras as well as 3D structure for urban targets. We present a 3D reconstruction of 1012 NYC photos processed in 4 hours on a 128-node cluster via "Photosynth" algorithms invented by Snavely et al (2006, 2009).

We next georegister the ground-level city photos by combining their reconstructed relative 3D coordinates with corresponding world-space information from a laser radar map. Qualitatively good alignment between

the independent 2D and 3D imagery is illustrated via a computer graphics viewer which zooms into reconstructed photos and fades them away to reveal background ladar data correspondences. The absolute angular error in our photo georegistration is quantified at 0.1 degree.

Once a 3D framework for analyzing 2D photos is adopted, many difficult urban imagery exploitation problems become mathematically tractable. We present three examples of geometry-based exploitation of geospatially organized city photos which are very difficult to perform via conventional image processing: urban feature annotation, image-based querying and photo segmentation. High-level urban knowledge such as building names, absolute geopositions and region classification projects from 3D world-space into georegistered 2D image planes and propagates between different photos.

Such automatic capabilities lay the groundwork for real-time labeling of photos shot in complex city environments by mobile smart phones.

Finally, we close with future military applications of this work. They include urban mission planning, autonomous robot navigation and UAV video monitoring.

7697-41, Session 9

An evaluation of GPU acceleration for sparse reconstruction

T. R. Braun, National Geospatial-Intelligence Agency (United States)

Image processing applications typically parallelize well. This gives a developer interested in data throughput several different implementation options, including multiprocessor machines, general purpose computation on the graphics processor, and custom gate-array designs. Herein, we will investigate these first two options for dictionary learning and sparse reconstruction, specifically focusing on the K-SVD algorithm for dictionary learning and the Batch Orthogonal Matching Pursuit for sparse reconstruction. These methods have been shown to provide state of the art results for image denoising, classification, and object recognition. We'll explore the GPU implementation and show that GPUs are not significantly better or worse than CPUs for this application.

7697-42, Session 9

Planar surface detection and extraction in image pair taken under urban environment

Q. He, Mississippi Valley State Univ. (United States); H. Chu, Univ. of Louisiana at Lafayette (United States)

Planar surfaces are important characteristics in man-made environment, in particular, under urban environment. They abound in buildings and architectural structures, in indoor environments, and are found on most manufactured objects. Planar surfaces encapsulate two-dimensional information of objects and have been successfully applied to camera calibration and interactive modeling. Here we develop a method for detecting and extracting planes in image pairs taken under urban environment. The projected planar surfaces in image pair are related by a planar homography (a 3 by 3 matrix), which can be computed from feature point correspondences. Since the planar homography has eight degrees of freedom, three point correspondences is needed to compute it. In practice, we have a set of feature point correspondences. In our algorithm, we first roughly estimate the planar homography using RANSAC method on three point correspondences. Next, we find the most number of matched points satisfied with the estimated planar homography. Then we apply the Levenberg-Marquardt algorithm on those matched points to solve the more accurate planar homography. The imagery captured from urban environment is full of planar surfaces from man-made buildings and architectural structures. Those surfaces detected in image pair and satisfied with a planar homography will be detected as planar surfaces. We illustrate the algorithm's performance on gray-level and color image pairs.

7697-43, Session 9

Hierarchical scene understanding exploiting automatically derived contextual data

K. Sullivan, S. Chandrasekaran, K. Solanki, B. Manjunath, J. Nayak, Mayachitra, Inc. (United States)

Scene understanding and object classification in aerial imagery is a difficult problem. Whereas in typical object classification scenarios, an image contains one dominant object, objects of interest in aerial imagery are typically surrounded by vast tracts of uninteresting background, and must be first detected then classified. Additionally many classes of interest are in fact comprised of many underlying visually distinct regions, and are only associated by semantic function.

In this paper we present methods for scene understanding and localization and classification of complex, visually heterogeneous objects from overhead imagery. Key features of this work include: determining boundaries of objects within large field of view images, classification of increasingly complex object classes through hierarchical descriptions, and exploiting automatically extracted hypotheses about the surrounding region to improve classification of a more localized region.

As an illustrative example, we note that typically image classifiers adopting commonly-used point descriptors based on local edge information will have difficulty discriminating between runways and freeways; both are generally flat with dominant lines in a single direction. If however it is determined the surrounding region is an airport, it is much more likely the local region should be classified as a runway. Our system uses a principled probabilistic approach to classify increasingly larger and more complex regions, and then iteratively uses this automatically determined contextual information to reduce false alarms and misclassifications.

7697-44, Session 9

Feature evaluation for target/background discrimination in image sequences taken by approaching sensors

R. Schöne, J. Meidow, E. Mauer, FGAN-FOM (Germany)

The conspicuity of different targets in image sequences taken by approaching sensors is addressed in applications such as the assessment of camouflage effectiveness or the performance evaluation of autonomous systems. In such evaluation processes the consideration of background characteristics is essential due to the propensity to confuse target and background signatures. Several discriminating features of target and background signature can be derived. Furthermore, the changing aspect and spatial resolution during an approach on a target have to be taken into account.

Considering salient points in image sequences, we perform a nominal/actual value comparison by evaluating the receiver operating characteristic (ROC) curve for the detections in each image. Hence, reference regions for targets and backgrounds are provided for the entire image sequence by means of robust image registration. The consideration of the uncertainty for the temporal progression of the ROC curve enables hypothesis testing for well-founded statements about the significance of the determined distinctiveness of targets with respect to their background. The approach is neither restricted to images taken by IR sensors nor applicable to low level image analysis steps only, but can be considered as a general method for the assessment of feature evaluation and target distinctiveness.

The analysis method proposed facilitates an objective comparison of object appearance with both, its relevant background and other targets, using different image analysis features. The feasibility and the usefulness of the approach are demonstrated with real data recorded with a FLIR sensor during a field trial on a bare and mock-up target.

7697-45, Session 9

Multi-eye input experiments for UAV image navigation and control

W. Baer, Naval Postgraduate School (United States)

The ability to rapidly and inexpensively register measured images to known databases in real time provides the basis for UAV mission control and image exploitation in previously unknown, to the operator, environments. Registration is generally the first function required in all Augmented Reality systems. Our experiment utilizes the ability of the human brain to generate a stereo 3d effect. However instead of using two real world images we use a real image coming from a UAV along with a synthetic image calculated from a terrain database. This technique uses a feedback loop implemented with the Perspective View Nascent Technology (PVNT) software package to provide operator control to establish and maintain the stereo illusion. Left and right eye inputs are delivered to an operator using a Liteye head mounted display driven by two separate computer programs.

The prototype system is mounted in a backpack along with communications interfaces which allow a field operator to receive UAV imagery and telemetry and both send commands to a UAV as well as products from image exploitation functions to an SA display in the command and control center. The results of field experiments testing the accuracy and facility with which the dual eye stereo effect can be used to register, control and exploit UAV imagery will be presented by the author.

7697-46, Session 9

Analysis of human motion in video imagery

A. M. Thomas, J. M. Cathcart, Georgia Institute of Technology (United States)

Human motion in visual and long-wave infrared video imagery is investigated. A simple moving target tracker is used to segment out the subject of interest in a video sequence. Pixel level changes of the subject's size and position within the image are then used to form a pair signals. Standard techniques in signal processing are then applied to find features of interest. The long term goals of the work are to find a means for associating tracks of humans in optical video data with poorly resolved micro-Doppler RF signals, and to determine intent.

7697-47, Session 10

Neurally inspired rapid detection of sparse objects in videos

D. Khosla, D. Huber, R. Bhattacharyya, M. Daily, P. Tasinga, HRL Labs., LLC (United States)

In this paper, we describe COGNIVA, a closed-loop Cognitive-Neural method and system for image and video analysis that combines recent technological breakthroughs in bio-vision cognitive algorithms and neural signatures of human visual processing. COGNIVA is an "operational neuroscience" framework for intelligent and rapid search and categorization of Items Of Interest (IOI) in imagery and video.

The IOI could be a single object, group of objects, specific image regions, specific spatio-temporal pattern/sequence or even the category that the image itself belongs to (e.g., vehicle or non-vehicle). There are two main types of approach for rapid search and categorization of IOI in imagery and video. The first approach uses conventional machine vision or bio-inspired cognitive algorithms. These usually need a predefined set of IOI and suffer from high false alarm rates. The second class of algorithms is based on neural signatures of target detection. These algorithms usually break the entire image into sub-images and process EEG data from these images and classify them based on it. This approach may suffer from high false alarms and is slow because the entire image is chipped and presented to the human observer. The proposed COGNIVA

overcomes the limitations of both methods by combining them resulting in a low false alarm rate and high detection with high throughput making it applicable to both image and video analysis.

In the most basic form, COGNIVA first uses bio-inspired cognitive algorithms for deciding potential IOI in a sequence of images/video. These potential IOI are then shown to a human and neural signatures of visual detection of IOI are collected and processed. The resulting signatures are used to categorize and provide final IOI. We will present the concept and typical results of COGNIVA for detecting Items of interest in video data.

7697-48, Session 10

Integrated optic chip for laser threat identification

A. D. McAulay, Lehigh Univ. (United States)

The increased use of lasers in the military for range finding, target designation, communications, dazzle, location of targets, munitions-guidance, and destruction requires accurate robust laser warning devices on military systems to detect and identify lasers striking them in order to assess their threat level. At last year's conference, April 2009, paper 7226-57, we discussed this problem and possible solutions, grating, wavefront, and Fizeau interferometers. In this paper we design an integrated optic spectral analyzer chip that is far more robust, reliable and provides more accurate spectral estimation than the approaches shown last year. It is a totally passive device of silicon which means that it could be buried in sand and will operate years later. The input light is channeled via a fiber pigtail into the integrated optic chip input. The many discrete laser wavelengths at the input to the integrated optic chip are separated into frequency channels at separate outputs. The integrated optic chip consists of a star coupler that fans out amongst waveguides of different length followed by a star coupler at the end of all the waveguides that focuses different wavelengths to different outputs in order to separate them. Design equations are derived to cover a range of frequencies at specific frequency spacing relevant to this application. The concept is based on the array waveguide grating device used for demultiplexing in fiber telecommunications.

[1] A. D. McAulay, A., D., Optical Computer Architectures, Wiley-Interscience, New York, (1991).

[2] A.D. McAulay, ``Detecting modulated lasers in the battlefield and determining their direction," Signal Processing, Sensor Fusion, and Target Recognition XVIII, SPIE Proceeding 7336-57, April 2009

7697-49, Session 10

Maximum likelihood periodogram for detecting radar signals

S. A. Shedied, Egyptian Armed Forces (Egypt)

Detection and signal processing of radar signals have been in the focus of signal processing research area for many years and still due to the challenges encountered in the field such as hardware implementation issues, performance of the detector in the presence of different types of noise, etc.... Based on that, several techniques for estimating the spectrum of radar signal were developed such as , non-parametric techniques, parametric techniques and sub space techniques. Due to the ease of hardware implementation and performance superiority, the peak detector or what is called the standard periodogram was found to provide a satisfactory performance especially in case of CW radar waveform. Because of the above mentioned advantages in addition to the fact that the periodogram does not require a prior knowledge of the Power Spectral Density (PSD) of the desired received signal, different variations of the standard periodogram are presented such as ; the modified periodogram, Bartlett, and Welch methods. Unfortunately, the periodogram and so its variations, is a biased estimator of the PSD. So, its performance degrades remarkably in the presence of jamming. To overcome this problem an estimation of the PSD based on maximum

likelihood estimators is introduced in this paper instead of the usual averaging technique used in the periodogram method and its variations. In the paper, an introduction of the maximum likelihood estimators used in the proposal will be presented. Then, the proposed maximum likelihood periodogram method will be introduced. Finally, the performance of the new detector will be compared to some of the most popular radar signal detectors.

7697-50, Session 10

Target detection for through the wall radar imaging

A. A. Mostafa, A. M. Zoubir, Technische Univ. Darmstadt (Germany)

We consider the problem of through the wall radar imaging when no a priori knowledge about the image statistics is available. The approach presented in this paper allows for automatic target detection. It integrates Independent component analysis (ICA) to reduce clutter and noise artifacts, spatial features, and histogram based thresholding. For clutter and noise reduction it is assumed that, the scattered response is composed of superposition of responses from individual scatterers, i.e., we assume a linear model. Thus, mainly three components occur: Measurement noise, clutter, and reflection from a desired target. Other unwanted contributions like antenna cross talk, wall reflection and multiple reflections are considered as clutter. Thus, using ICA, the source signal can be decomposed into target and clutter, Image that contains target information can be chosen, and the remaining is discarded. Next, a multi step histogram based thresholding is done. First, a brightness level thresholding step is done for the whole 3D image. Second, disconnected objects volume thresholding is used to remove small volume objects. Third, brightness level thresholding of each disconnected object is done, as noise levels may differ from object to another. The proposed detection schemes are evaluated using real data and synthesized data and produced target detection rates of 60-70%.

7697-51, Session 11

Optimal waveforms for MIMO radar systems employing the generalized detector

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

We consider the problem of waveform design for multiple-input multiple-output (MIMO) radar systems constructed based on the generalized approach to signal processing in noise, where the transmit waveforms are adjusted based on target and clutter statistics. We design a model for the radar returns which incorporates the transmit waveforms developed. The target detection problem is formulated for that model in accordance with the generalized approach to signal processing in noise and we designed a structure of the generalized detector for specific initial conditions. Optimal and suboptimal algorithms based on the generalized approach to signal processing in noise are derived for designing the transmit waveforms under different assumptions regarding the statistical information available to the generalized detector. The performance of these algorithms is illustrated by computer simulation. We focus our work almost entirely on the point target model, and assume transmission of orthogonal signals on different antennas of MIMO radar system. This makes it possible to separate the signals arriving from the different transmit antenna at the receiver, and to perform any transmit array processing functions on the receive side "after the fact". However, the coherent transmitter array gain is lost when doing the transmit beamforming after, rather than during, transmission. Employing adaptive processing by the generalized detector, it is possible to improve clutter rejection in ways that not possible in conventional radar systems. MIMO radar systems constructed based on the generalized approach to signal processing can also provide angular diversity which is useful in some scenarios. We also consider the waveform design problem for MIMO radar systems based on the generalized approach to signal processing in noise for the case of an extended target, and without limiting ourselves

to orthogonal waveforms. Instead we develop a procedure to design the optimal waveform which maximizes the signal-to-interference plus-noise ratio (SINR) at the output of the generalized detector constructed in accordance with the generalized approach to signal processing in noise. The optimal waveform requires knowledge of both target and clutter statistics. We also develop several suboptimal waveforms requiring knowledge of target statistics only, clutter statistics only, or both.

7697-52, Session 11

A novel technique for data security in optical code division multiple access network using dode-hopping technique

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A theoretical study on code-hopping technique in optical code division multiple access (OCDMA) network is reported. The need for error-free, high capacity, highly secured and high-speed communication channels at low cost has been on the rise. OCDMA technology is rapidly becoming a technology-of-choice to meet the above demands. Most of the present day OCDMA communication systems use permanent mask for encoding/decoding of the data. To maintain a high degree of security dynamic masking is obvious. In this communication we propose a novel technique of dynamic masking that makes use of Code hopping. Code hopping assigns different codes for different stations both in transmitting and receiving ends in a random fashion. Here, dynamic masking by micro-controller based spatial light modulators in the encoder/decoder is proposed. A theoretical analysis in terms of capacity of the system is presented. The system utilizes unipolar Walsh coding.

7697-53, Session 11

Signal-to-noise calculations of munition muzzle flashes at various bandpasses

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An analysis is performed, using MODTRAN, to analyze the muzzle flash of AK-47 rounds and tank rounds to optimize the signal-to-noise ratio and the filter bandpass by comparing filters of various bandwidths. Filters of different bandpasses are evaluated near the 766.5 nm and 770.1093 nm potassium emission lines, which are observed using spectral measurements, during the discharge of many munitions. The setting is in a desert environment in the daytime. The maximum spectral radiance of the tank muzzle flash was 0.016 W/cm2*str*micron and the two emission lines are not well separated. On the other hand, the AK47's maximum spectral radiance of 3.83 x 10-5 W/cm2*str*micron is much smaller and the individual emission lines are discreet and well separated. As expected, the larger bandpasses result in lower signal-to-noise ratios, as the larger bandpasses permit the passage of atmospheric radiance, which is the source of noise, through the filter. Elemental abundances are also evaluated to understand which elements contribute the most to the atmospheric spectral radiance. Detection of the tank muzzle flash is easily achieved with a 5 nm bandpass filter centered at 768.13 nm, resulting in a signal-to-noise ratio of 15005. At the other extreme, even a 0.05 nm bandpass filter, used to view the AK-47 muzzle flash only results in a signal-to-noise ratio of 4.09 x 103.

7697-56, Session 11

Target detection from MPEG video based on low-rank filtering in the compressed domain

T. Viangteeravat, The Univ. of Tennessee Health Science Ctr. (United States); S. Krootjohn, King Mongkut's Univ. of Technology (Thailand); D. M. Wilkes, Vanderbilt Univ. (United States)

There are the advantages of using the motion vector obtained from the MPEG video coding to perform target of interest identification in the field. In practice, however, many environment noise, time-varying, and uncertainties factors affect their performance in detecting targets of interest reliably and accurate. In this paper, we have proposed a novel low rank filtering based on norm in order to straighten up single rogue or outliers that we found might show up fairly often. Finally, a simple average smoothing filter is applied to reduce vector quantization noise correct for vectors that have been filtered. Using the low rank filtering based norm, the dominant motion vector from the MPEG video coding can be extracted appropriately with respect to target operational responses and used for robust identification of moving target. The performance of the proposed approach has been evaluated based on the set of experimental camera motion. The camera motion pan, tilt, and zoom are computed from the motion vectors, and the residual vectors which are not described by the camera motion are regarded as generated by moving blobs. Events are detected from these moving blobs. It is demonstrated that the approach yields very promising results where motion vector obtained from the MPEG video coding are used to detect, identify moving target in the field.

7697-57, Session 11

Modified noncausal smoothing filter and low-rank matrix approximation for noise reduction

T. Viangteeravat, The Univ. of Tennessee Health Science Ctr. (United States); D. M. Wilkes, Vanderbilt Univ. (United States)

Removing noise in real time has become a high priority for analyzing data corrupted by additive noise. It is a major problem in various applications such as speech, image processing and real time multimedia services. Although considerable interest has arisen in recent years regarding wavelets as a new transform technique for many applications, the linear adaptive decomposition transform (LDT) [10] has yielded results superior to the discrete wavelet transform (DWT) [13,14] not only in terms of using a lower number of decomposition levels but also achieving a smaller percentage normalized approximation error in the reconstructed signal. In this paper, a novel noise reduction method, based on a modified noncausal smoothing filter and low rank approximation based upon the sum of minimum magnitude error criterion (i.e., norm) is introduced that distinguishes itself from these other methods. The performance of the proposed approach was evaluated based on one dimensional data sets studied by Donoho and Johnstone [13,14] as well as speech samples. It is demonstrated that the approach yields very promising results on the test signals of the Donoho and Johnstone as well as to speech signals.

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7698-01, Session 1

A complex-domain adaptive order statistic filter and its application to signal detection in non-Gaussian noise and clutter

M. F. Fernández, T. Aridgides, Lockheed Martin Maritime Systems & Sensors (United States)

This paper presents an adaptive Order-Statistic Filter (OSF) that can operate in the real and the complex data domains to maximize the gain in signal to noise and/or clutter ratio. This distribution-independent nonlinear filter approximates the optimal filter when the background is not Gaussian (e.g., speckle-type clutter, Gamma noise, etc.), producing a "Gaussianized" residual that ensures the near-optimality of subsequent processing stages that assume Gaussian statistics (e.g., background-normalization/CFAR, signal classification, etc.). Furthermore, the residual resulting from an adaptive OSF stage can implicitly be re-filtered, driving the ensuing residuals ever closer to being Gaussian-distributed. The output of such recursive version of our adaptive OSF will thus approximate optimality in the maximum likelihood sense (e.g., in the case of signal detection, by maximizing Pd while minimizing Pfa).

Clearly, adaptive OSFs can be of great utility; however, the general applicability of the formulations currently found in the literature is curtailed by serious deficiencies such as their lack of means for: (1) ordering complex data, (2) preserving general signals of interest, (3) ensuring better performance than classical ("linear") adaptive methods, and (4) maintaining computational requirements at manageable levels.

Our adaptive OSF overcomes these difficulties by exploiting isomorphisms and orthonormal transformations to surpass the performance of the classical adaptive formulation while ensuring the preservation of any signal of interest. Moreover, our procedure can be easily extended to the complex data domain to address coherent applications such as hologram processing, adaptive beamforming, matched filtering, Doppler filtering, etc. Finally, except for its data-sorting stage, the complexity of our adaptive OSF is comparable to that of other classical adaptive algorithms.

7698-02, Session 1

Joint forward and reverse importance sampling by temporal folding for efficient evidence accumulation in track before detect

F. Porikli, H. Ozkan, Mitsubishi Electric Research Labs. (United States)

In this contribution, we extend the particle filter based TBD to dual direction accumulation, i.e. reverse and forward in time, to improve the detection performance under very-low signal-to-noise ration conditions for non-linearly and irregularly moving pixel sized targets. In other words, our algorithm applies these stages given multiple observations: In the first observation, we generate a certain number of hypotheses in our state space according to the likelihood values as computed above. Basically, these particles are the highest likelihood locations. We do not initiate any continuing particles as no previous frame exists. In the following frames, we update the continuing particles. We only assume motion is relatively small within a search window around a particle and analyze the likelihood values for each particle. In case the updated likelihood is significant the particle is declared as to be alive. These windows, in a way, allow inclusion of noise on our motion settings. We update the weights of the continuing particles, remove the unimportant ones, regenerate new particles, and carry out the above steps forward in time. To prevent from excessive number of particles, we subsample among the particles

at each iteration level. We keep pointers to the tracks of each particle. When we reach to the final observation, we fold time, that is, reverse the temporal order and repeat the particle filter starting from the last frame to foremost as opposed to the conventional method. We, then, combine the final tracks, not just the particle weights, using their accumulated confidences to determine the final detection results. Our comprehensive experiments demonstrate that the joint algorithm can successfully detect and track point targets, almost 27% more accurately than the conventional particle filters.

7698-03, Session 1

Small moving targets detection using outlier detection algorithms

N. Reljin, N. Pejcic, D. Pokrajac, Delaware State Univ. (United States); A. Lazarevic, United Technologies Research Ctr. (United States); L. J. Latecki, Temple Univ. (United States); T. Vance, Delaware State Univ. (United States)

We propose use of incremental connectivity-based outlier factor (incCOF) and incremental local outlier factor (incLOF) algorithms and compare them with a pixel-wise motion detection method based on dynamic distribution learning. The proposed approaches detect moving objects as outliers in properly defined attribute space. The outliers are objects which are distinct from the objects in their neighborhood. For incLOF and incCOF, each video is represented with spatial-temporal blocks on which principal component analysis (PCA) is applied in order to reduce the dimensionality. In the pixel-wise motion detection method, groups of pixels are selected that correspond to moving objects. Moving objects are detected based on the displacement of the selected points, which is computed using optical flow technique. We develop an objective measure of detection accuracy based on measuring false positive and false negative rates and evaluate our algorithms on RGB and infrared sequences from SENSIAC database, PETS repository and data collected at Delaware State University from FLIR Systems PTZ35*140 cameras.

7698-04, Session 1

MIMO radar systems based on the generalized detector and space-time coding

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper we consider the problem of multiple-input multiple-output (MIMO) radars employing the generalized detector based on the generalized approach to signal processing in noise and using the space-time coding to achieve desired diversity. To that end, we derive a suitable generalized detector structure after briefly outlining the model of the received target return signal. The generalized detector performance is expressed in closed form as a function of the clutter statistical properties and of the space-time code matrix. We investigate a particular case when the generalized receiver requires a priori knowledge of the clutter covariance, i.e., the decision statistics, under the null hypothesis of no target, is an ancillary statistic, in the sense that it depends on the actual clutter covariance matrix, but its probability density function (pdf) is functionally independent of such a matrix. As a consequence, threshold setting is feasible with no a priori knowledge as to the clutter power spectrum. As to the detection performance, a general integral form of the detection probability is provided, holding independent of the target fluctuation model. The formula is not analytically manageable, nor does it appear to admit general approximate expressions which allow giving an insightful look in the system behavior. We thus restrict our attention to the case of Rayleigh-distributed target attenuation (Swerling-1 model), and derive the Chernoff bound for the detection probability, which turns

out to be a useful tool for space-time coding design. We also propose an information-theoretic approach to code construction which leads to the same solution found through optimization of the Chernoff bound. These two last points are the major innovations of the present study, since they offer a methodological framework for space-time coding in MIMO radar systems, as well as simple and intuitive bounds for performance prediction.

7698-05, Session 2

Comparison of swarm intelligent algorithm with nonnegative weighted least squares for Raman spectra estimation

N. Srinivas, Syracuse Univ. (United States); M. Mallick, Georgia Tech Research Institute (United States); L. A. Osadciw, Syracuse Univ. (United States)

Raman spectroscopy is a powerful technique for determining the chemical composition of a substance. Our objective is to determine the chemical composition of an unknown substance given a reference library of Raman spectra. The unknown spectrum is expressed as a linear combination of the reference library spectra and the non-zero mixing coefficients represent the presence of individual substances, which are not known. This is also known as supervised method. The mixing coefficients are usually estimated using the nonnegative least squares (NNLS) or nonnegative weighted least squares (NNWLS). This problem is a constrained estimation problem due to the presence of the nonnegativity constraint. In this paper, we present a swarm based algorithm, the particle swarm optimization (PSO), to estimate the mixing coefficients and Raman spectra. The PSO is used to determine the mixing coefficients as a function of required accuracy.PSO efficiently finds an optimum solution. Results are presented for simulated data obtained from the Jennifer Kelly Raman Spectral library. The reference library consists of Raman spectra for nine minerals and the measured spectrum is simulated by using spectrum/spectra of single/multiple minerals. The performance is measured by comparing the root mean square error (RMSE) for parameter estimation and measurement residual and computational time of the NNWLS and PSO algorithms.

7698-06, Session 2

Identifying chemicals from their Raman spectra using minimum description length

R. D. Palkki, A. D. Lanterman, Georgia Institute of Technology (United States)

Raman spectroscopy has been a powerful means of chemical identification in a variety of fields, partly because of its non-contact nature and the speed at which measurements can be taken. Given a library of known Raman spectra, a common detection approach is to first estimate the relative amount of each chemical present, and then compare the estimated mixing coefficients to an ad hoc threshold. We present a more rigorous detection scheme by formulating the problem as one of Multiple Hypothesis Detection (MHD) and using the maximum a posteriori (MAP) decision rule to minimize the probability of classification error. The probability that a specific target chemical is present is estimated by summing the estimated probabilities of all the hypotheses containing it. Alternatively, since we do not typically have reasonable priors for the hypotheses, it is perhaps preferable to interpret the result as an abstract score corresponding to the Minimum Description Length (MDL). We reduce the hypothesis space by applying realistic prior knowledge about the scenario. The resulting detection performance of this approach is compared to that of several other supervised classification algorithms.

7698-07, Session 2

Wavelet-based denoising and baseline correction for enhancing chemical detection

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Various chemical agents have been known to provide unique Raman spectrum signatures. Practical methods for chemical detection have to deal with cluttered data where the desired agent's signature is mixed with those of other chemicals in the immediate environment. Linear mixture models have been proposed for isolating the agent's signature from such data. It has been found that unmixing is affected by strong background signatures, such as those from the substrate, and noise. This work proposes the use of denoising and baseline correction techniques to enhance the probability of detection of a desired agent. The baseline correction is applied to minimize the contribution of the background. Wavelet transform based techniques were investigated for this purpose. These approaches varied in their choice of wavelets, denoise thresholds, and baseline suppression approaches. Their efficacies in chemical detection were assessed with experimental Raman spectroscopic data using metrics and tools such as detection rates, false alarm rates, positive predictive values, negative predictive values and receiver operating curves. It was found that linear denoising and baseline correction, effected through appropriate amplitude scaling of various wavelet bands, provide significantly improved performance whereas a nonlinear approach such as hard or soft thresholding often leads to degradation. The paper provides a plausible theoretical explanation of this observation along with the detailed results.

7698-08, Session 2

Nonlinear estimation for arrays of chemical sensors

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Reliable detection of hazardous materials is a fundamental requirement of any national security program. Such materials can take a wide range of forms including metals, radioisotopes, volatile organic compounds, and biological contaminants. In particular, detection of hazardous materials in highly challenging conditions --- such as in cluttered ambient environments, where complex collections of analytes are present, and with sensors lacking specificity for the analytes of interest --- is an important part of a robust security infrastructure. Single sophisticated sensor systems provide good specificity for a limited set of analytes, but often have cumbersome hardware and environmental requirements. On the other hand, simple, broadly responsive sensors are easily fabricated and efficiently deployed, but such sensors individually have neither the specificity nor the selectivity to address analyte differentiation in challenging environments. However, arrays of broadly responsive sensors can provide much of the sensitivity and selectivity of sophisticated sensors, but without the substantial hardware overhead. Unfortunately, arrays of simple sensors are not without their challenges --- the selectivity of such arrays can only be realized if the data is first distilled using highly advanced signal processing algorithms. In this paper we will demonstrate how the use of powerful estimation algorithms, based on those commonly used within the target tracking community, can be extended to the chemical detection arena. In particular, our focus is on algorithms that not only provide accurate estimates of the mixture of analytes in a sample, but also provide robust measures of ambiguity, such as covariances.

7698-09, Session 2

Optimization of a chemical identification algorithm

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Li, S. MacDonald, A. Slamani, S. A. Mitchell, J. Pendell-Jones, T.
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A procedure to optimize the performance of a chemical identification
algorithm is presented. The Joint Contaminated Surface Detector
(JCSD) employs Raman spectroscopy to detect and identify surface
chemical contamination. JCSD measurements of chemical warfare
agents, simulants, toxic industrial chemicals, interferents and bare
surface backgrounds were made in the laboratory and under realistic field
conditions. A test data suite was developed from these measurements
to benchmark algorithm performance throughout the improvement
process. In any one measurement, one of many possible targets can be
present along with interferents and surfaces. The detection results are
expressed in the terminology of a binary classification problem so that
Receiver Operating Characteristic (ROC) techniques can be applied.
The limitations of applying this framework to the chemical detection
problem are discussed along with methods to address them. Algorithmic
sensitivity and selectivity are optimized globally using robust Design of
Experiments and Taguchi techniques. These methods require figures of
merit to trade off between false alarms and detection probability. Several
figures of merit, including the Matthews Correlation Coefficient and a
Taguchi Signal-to-Noise metric are compared and a subset chosen for
use in the analysis. Following the optimization of global parameters
which govern the algorithm behavior across all target chemicals, ROC
techniques are employed to optimize chemical-specific parameters to
further improve performance for specific target chemicals.

7698-10, Session 2

Comparative studies of Raman spectra estimation algorithms for single and multiple chemical substances

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Raman spectroscopy has received a great deal of attention in recent
years in the Chemical and Biological detection research community
because of its unique ability to determine the chemical composition
of substances. This has led to development of fast and numerically
efficient algorithms for Raman spectra estimation. There are three
types of algorithms for Raman spectra estimation; the supervised and
unsupervised. In the supervised approach, a set of reference spectra
for a number of known substances is used. It is then assumed that the
measured spectrum of an unknown substance belongs to one of the
individual substances in the reference library or arises from a linear
combination of a number of reference spectra. The mixing coefficients for
a measured spectrum are usually estimated using the nonnegative least
squares (NNLS) or nonnegative weighted least squares (NNWLS). This
parameter estimation problem is a constrained estimation problem due
to the presence of the nonnegativity constraint on mixing coefficients.
Earlier, researchers used the NNLS where no weight matrix was used
or all measurement error variances are treated as equal. In our Fusion
2009 paper, we found that the measurement error variances or weights
vary significantly with the wavenumber and that it is necessary to use
the non-uniform weights in parameter estimation. Previously we used the
true weights and have done limited study using estimated weights. In this
paper, we perform extensive study for Raman spectra estimation using
NNLS and NNWLS for single and multiple chemical substances using
simulated data and Monte Carlo simulations with weights estimated from
the data.

7698-11, Session 2

Tracking interacting dust: comparison of tracking and state estimation techniques for dusty plasmas

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Complex (dusty) plasmas are a convenient mesoscopic test bed for
exploring the kinematics of microscopic systems in different phases
(fluid-like, crystal-like). Micron-sized 'dust' grains within an ion-electron
plasma interact with each other via a screened Coulomb interaction.
These dust-dust interactions are the principal effect in the observed
particle dynamics. This work investigates the accuracy of measurement
and tracking techniques in the presence of complex nearest-neighbour
interactions and how modern state estimation methods based on
the Kalman filter can be used to monitor this complex system. The
principal requirement is to simplify the tracking algorithms to reduce
the computational costs without reducing the accuracy of the particle
tracks. A balance was found between accuracy of the measurements and
accuracy of the particle tracks.

7698-42, Poster Session

Algorithms for distributed chemical sensor fusion

R. C. Paffenroth, S. Lundberg, J. Yosinski, Numerica Corp.
(United States)

Coordination and merging of multiple distributed sensors over a
communications network can substantially improve estimates of the type
and severity of potential chemical, biological, radiological, and nuclear
(CBRN) hazards for command and control decision makers. These
sensors include long range instruments such as radar, infrared, electro-
optical, and long wave hyper spectral; short range instruments such as
Raman spectrometers; and a wide array of point sensors such as,ion
mobility spectrometers (IMS) and chemical-resistor arrays.

However, in order to fully utilize this rich collection of data for threat
detection and characterization, advanced algorithms are required for
data fusion as such fusion is an important part of C2 decision making in
weapon of mass destruction scenarios. While estimation schemes for
various components of CBRN detection problems are quite common,
what is much less common are estimation schemes that provide
appropriate measures of uncertainty or ambiguity. Such ambiguity
measures are of prime importance in sensor fusion problems when one
is merging data from sensors with varying levels of trust worthiness. In
such cases appropriate measures of ambiguity are key to the effective
fusion of data from disparate sensors. Another domain in which precisely
the same types of problems arise is that of distributed target tracking and
it is methods from this domain, such as non-linear maximum likelihood
estimation and recursive filtering based on derivatives of the Kalman
filter, that we demonstrate here for use in distributed CBRN detection
problems.

7698-44, Poster Session

A tracker adjunct processing system for reconsideration of firm tracker decisions

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(United States)

Most modern maximum likelihood multiple target tracking systems
(e.g., MHT and MFA) need to determine how to separate their input
measurements into subsets corresponding to the observations of
individual targets. These observation sets form the tracks of the system,
and the process of determining these sets is known as data association.

Time pressures frequently force the use of only the maximum likelihood choice for data association, although alternative data association choices may have been considered in the process of choosing the most likely.

This paper presents a Tracker Adjunct Processing (TAP) system that captures and manages the uncertainty encountered in making data association decisions. The TAP combines input observation data and the data association alternatives considered by the tracker into a dynamic Bayesian network (DBN). The network efficiently represents the combined alternative tracking hypotheses (as a graph instead of a tree). Bayesian network evidence propagation methods are used to update the network in light of new evidence, which may consist of new observations, new alternative data associations, newly received late observations, hypothetical connections, or other flexible queries.

The maximum likelihood tracking hypothesis can then be redetermined, which may result in changes to the best tracking hypothesis. The recommended changes can then be communicated back to the associated tracking system, which can then update its tracks. In this manner, the TAP reconsiders and possibly changes the firm, fixed (formerly maximum likelihood) decisions of the tracker. The TAP can also assess (and reassess) track purity regions by ambiguity level.

7698-45, Poster Session

On-road obstacle detection and tracking system using high-accurate stereo matcher

S. Kwon, J. Lee, Daegu Gyeongbuk Institute of Science & Technology (Korea, Republic of)

Stereo vision is widely used in existing vision-based intelligent vehicles and driver assistance systems. Range information from stereo vision is essential for many vehicle applications such as autonomous navigation, stop-and-go, obstacle localization, and collision avoidance. In moving vehicle applications, vision systems are required to have both high accuracy and fast processing speed, which is a very difficult trade-off problem, especially for stereo vision-based systems.

In this paper, we introduce global stereo vision-based on-road obstacle detection and tracking system which shows robust and reliable performance under general traffic environments. To meet the goal, we applied a robust stereo matcher, an obstacle detector, and a tracker module are implemented and tested under actual driving conditions.

Stereo matcher consists of two main parts - matching cost calculator and optimizer. Matching cost calculator is based on normalized cross correlation (NCC) to enhance accuracy and reliability of the system. Our optimizer used a global matching method based on the Hierarchical belief propagation (HBP). Global matching approaches are usually avoided in vehicle applications because they require heavy computational burden, making real-time system intractable. However, current stereo vision studies based on parallel processing are able to offer accurate depth maps in real-time, or semi real-time.

In our obstacle detector, which use a v-disparity-based method, has 4 steps for obstacle detection. First, v-disparity and u-disparity images are constructed using a disparity image from a stereo matcher. In the next step, a line segment in v-disparity image that corresponds to the road in the scene, which is called the road profile, is detected by Hough transform. Then, road region is segmented and removed from region of interest and vertical line segments in v-disparity image are extracted using Hough transform. In the final step, the width of the bounding box is found by extracting horizontal line segments from the u-disparity image.

For efficient tracker, we used the detect-and-track method by tracking pre-detected obstacles in the current frame, which results that the region for exhaustive search can be reduced dramatically.

By applying robust techniques to a realistic situation, our system successfully extracted accurate and reliable depth information in various practical imaging situations. Our detection and tracking system shows invariant performance under cluttered background or complicated scenes, while it is very sensitive to obstacle-like structures and background objects.

7698-46, Poster Session

The optimal algorithm for asynchronous track-to-track fusion

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Most existing track-to-track fusion (T2TF) algorithms for distributed tracking systems are given assuming that the local trackers are synchronized. However, in the real world, synchronization can hardly be achieved and local trackers usually work in an asynchronous fashion, where local measurements are obtained and local tracks are updated at different times with different rates. Communication delays between local trackers and the fusion center (FC) also cause delays in the arrival of the local tracks at the FC. This paper presents the optimal asynchronous T2TF algorithm for distributed tracking systems under the linear Gaussian (LG) assumption, which is also the linear minimum mean square error (LMMSE) fuser without the Gaussian assumption. To illustrate the algorithm, a basic scenario of the fusion of two asynchronous local tracks is used, where one is available at the FC with no delay and the other is transmitted from a local tracker with a time delay. The algorithm can be extended to scenarios with more than two local trackers. The optimal asynchronous T2TF algorithm is compared with the approximate algorithms in [1] and is shown to have performance benefit in both consistency and fusion accuracy.

Ref: [1] A. Novoselsky, S. E. Sklarz and M. Dorfan, "Track to track Fusion using Out-of-Sequence Track Information", Proc. 10th International Conference on Information Fusion, Quebec City, Canada, July 2007.

7698-47, Poster Session

Filtering for very long-range radars using particle filter and Gaussian sum filter

M. Mallick, T. Huang, Georgia Tech Research Institute (United States)

Previous work on filtering for very long range radars using (r,u,v) measurements has shown that this problem poses certain difficulties including covariance inconsistency for conventional filtering algorithms such as the extended Kalman filter (EKF), converted measurement Kalman filter with first order Taylor expansion (CM1KF), converted measurement Kalman filter with second order Taylor expansion (CM2KF), and unscented Kalman filter (UKF). A measurement covariance adaptive EKF (MCAEKF) provides satisfactory state estimates and covariances. This paper uses the particle filter (PF) and Gaussian sum filter (GSF) for this problem. We shall compare the results of the PF and GSF with with those from existing filtering algorithms using Monte Carlo simulations.

7698-48, Poster Session

Multipath-assisted multitarget tracking with reflection point uncertainty

M. Subramaniam, R. Tharmarasa, McMaster Univ. (Canada);
M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)

In this paper, the previous work multipath-assisted multitarget tracking using multiframe assignment is extended to the case where the multipath reflection points are unknown to the receiver. An algorithm is proposed for initiating and tracking multiple targets using multiple transmitters and receivers. This algorithm is capable of exploiting multipath target returns from distinct and unknown propagation modes. When multipath returns are not utilized appropriately within the tracker, (e.g., discarded as clutter or incorporated with incorrect propagation mode assumption) the potential information in the multipath returns is lost. In real scenarios, it is more necessary to assume that the locations of reflection points are unknown.

Integrating multipath information into the tracker by correctly identifying

the multipath mode and identifying the reflection point can help improve the accuracy of tracking. The challenge in improving tracking results using multipath measurements is the fusion of direct and multipath measurements from the common target when the multipath-reflection mode is unknown. The problem become even more challenging with false alarms and missed detections. We propose an algorithm to track the target with unknown multipath reflection points using the multiframe assignment technique. Simulation results are presented to show the effectiveness of the proposed algorithm on a ground target tracking problem.

7698-49, Poster Session

Wide-area feature-aided tracking with intermittent multisensor data

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Multi-sensor multi-target tracking and data fusion are technically challenging and vital components in military and security systems. In past research, NURC has developed a high-performance multi-stage multi-hypothesis tracking framework that has been fruitfully applied to undersea surveillance applications. More recently, we have extended this capability for maritime surveillance applications. This paper documents this technology and illustrates its real-time use in the Maritime Surveillance 09 (MS09) sea trial that was conducted in the eastern Mediterranean in October 2009.

Our past undersea surveillance activities were limited to local surveillance, scan-based data feeds, and non-cooperative targets.

Correspondingly, the principal extensions to our fusion algorithms for maritime surveillance include a global-tracking paradigm (each object has its own tangent-plane Cartesian coordinate system), flexible processing of scan-based and time-series data feeds, and enhanced association logic that accounts for cooperative and non-cooperative sensor data. The intermittency inherent in maritime surveillance data feeds provides a specific challenge that our enhanced track fusion logic is designed to address.

This paper provides a high-level algorithm description, a description of the MS09 sea trial, and initial surveillance performance results based on real-time processing onboard the NRV Alliance.

7698-53, Poster Session

Temporal characterization of small arms muzzle flash in the broadband visible

T. G. Burke II, D. Bratlie, Northrop Grumman Corp. (United States)

Various systems are under consideration to track point-of-origin of incoming small-arms fire. The tendency of these systems is to use either acoustic (e.g. report or projectile fly-by) or optical (e.g. muzzle flash or tracer tracking) methods to allow signal processing to determine point of origin. The authors have developed a simple system for characterizing the muzzle flash duration of common military small-arms ammunition as a feeder for system design configurations. This paper reports on the results of that characterization.

7698-54, Poster Session

Maneuverable threat defeat with distributed sensor concept (DISCO)

M. K. Rafailov, RICHER International LLC (United States)

Distributed Sensor Concept - DISCO was proposed to enhance probability of ballistic target engagement with multiple space-distributed weapon-sensors forming closed sensor network capable to exchange frame and GNC information. For DISCO there is no need in standoff sensor(s) coordinating weapon while target acquisition capability is equal or exceeding those operating with stand-off sensors. In the same time evenly distributed in space DISCO sensors create a tight grid that is capable to play a role of Agile Kill Vehicle that addressing maneuvering threats. In this presentation we will discuss ability of DISCO limited divert and attitude control capability sensors to form such a grid and to address the issue of maneuverable target defeat.

7698-56, Poster Session

Aided strapdown inertial navigation algorithm for autonomous underwater vehicles

Y. Liu, X. Li, The Univ. of New Orleans (United States)

This paper presents a navigation algorithm based on aided strapdown inertial navigation system (INS) for an underwater autonomous underwater vehicle (AUV). The AUV is equipped with a long baseline (LBL) acoustic positioning system, acoustic Doppler current profiler (ADCP) and a depth sensor to aid the INS. They have, however, much slower data rates than that of the INS. A linearized, quaternion-based dynamic model and measurement model of the INS output errors are presented. Data from different sensors are fused by applying the extended Kalman filer (EKF) to estimate and correct the errors. Due to the difficulty of generating realistic simulation scenario, real data (raw INS measurement) collected from AUV field experiments are processed to test the algorithm. Without knowing the ground truth, however, performance evaluation becomes much more complicated and needs further research. In this paper, the problem is circumvented by considering the post-processed real data as the ``ground truth" and the noisy raw measurement are generated from this ``ground truth" to feed the algorithm. The simulation results demonstrate the algorithm applicability and show that by incorporating readings from the ADCP and the depth sensor, the (horizontal) position errors still increase but with a significant lower rate than the case of stand-alone operation. If the LBL sensor is further included, the navigation errors can be constrained within a certain bound.

7698-50, Poster Session

Cross-range imaging of SAR and PDE analysis

Z. Qiao, J. Lopez, G. Garza, The Univ. of Texas-Pan American (United States)

In this paper, we present a deeper observation and clarification of the mathematics of cross range imaging of SAR data. We begin with an introduction to the cross-range SAR image scenario, and establish the relationship between the signal received by the radar antenna and the desired target function. We then evaluate the matched-filtered version of the target function by use of Fourier transforms. Sampling of the echoed signal is also discussed to introduce the concept of the radar system Pulse Repetition Frequency (PRF), and its affect on the digitized signal. A method of reducing the PRF via slow-time compression is also explained. Importantly, we present a detailed derivation of slow-time sample spacing, which corrects the previous formulation. A cross-range imaging algorithm and a comparison of the results are given based on our slow-time sample spacing. Finally, we discuss a mathematical model for SAR imaging - Maxwell's equations for SAR image reconstruction.

7698-51, Poster Session

A survey of maneuvering target tracking-part VIa: exact density based nonlinear filtering

X. Li, V. P. Jilkov, Univ. of New Orleans (United States)

This paper is part of Part VI of a comprehensive survey of maneuvering target tracking without addressing the so-called measurement-origin uncertainty. It provides a tutorial coverage of theoretical results of exact nonlinear filtering for estimating the probability density of the target state. They serve as theoretical basis for development of more practical nonlinear filters, covered in the other parts of this survey. An emphasis of this part is on those particularly suitable for handling nonlinearity in the system dynamics and/or observation systems encountered in target tracking, including finite dimensional exact filters.

7698-52, Poster Session

A survey of maneuvering target tracking-part VIb: approximate density based nonlinear filters

X. Li, V. P. Jilkov, Univ. of New Orleans (United States)

This paper is part of Part VI of a comprehensive survey of maneuvering target tracking without addressing the so-called measurement-origin uncertainty. It provides an in-depth coverage of various density-based nonlinear filters developed particularly for handling the uncertainties induced by potential target maneuvers as well as nonlinearities in the dynamical systems commonly encountered in target tracking. An emphasis is given to the more recent results, especially those with good potential for tracking applications. Approximate nonlinear filtering techniques for point estimation have been covered in a previous part, and sampling-based nonlinear filters will be surveyed in a forthcoming part.

7698-55, Poster Session

Impact point prediction for short-range thrusting projectiles

T. Yuan, Y. Bar-Shalom, P. K. Willett, Univ. of Connecticut (United States); D. F. Hardiman, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States)

This paper presents an interacting multiple model (IMM) based procedure to estimate the state of thrusting/ballistic projectiles in the atmosphere for the purpose of impact point prediction (IPP). The dynamic models for the thrusting and ballistic phase of a trajectory are presented. The modes of the IMM estimator are for the thrusting and the ballistic phases and different extended Kalman filters (EKF) are used as the mode-matched filters with different dimension states. A special novel procedure is used for the mixing of the estimates in the IMM. The IPP is achieved by using the IMM-predicted most probable mode at the mid-point of the trajectory.

The algorithm was developed based on real data obtained with a finite resolution radar for a large number of different rockets. The main difficulty was accounting for the radar's resolution. The results show that the predicted impact point falls in all these real data cases in a (99%) circular region calculated by the tracker. This region can be used for deciding whether to use countermeasures in an area defense system.

7698-57, Poster Session

The JPDAF in practial systems: approximations

K. Romeo, D. F. Crouse, Y. Bar-Shalom, P. K. Willett, Univ. of Connecticut (United States)

In this paper we look at various algorithms for approximating the target-measurement association probabilities of the the Joint Probabilistic Data Association Filter (JPDAF). We consider their computational complexity and compare their performance with respect to the Mean Optimal Subpattern Assignment (MOSPA) statistic in a scenario involving closely-spaced targets.

7698-12, Session 3

Track segment association for ground moving targets with evasive move-stop-move maneuvers

S. Zhang, Y. Bar-Shalom, Univ. of Connecticut (United States)

In a tracking system, track breakages can occur due to highly maneuvering targets, low detection probability, or clutter.

Previously, a track segment association approach (TSA) was developed for an airborne early warning (AEW) system to improve track continuity by ``stitching'' broken track segments pertaining to the same target. In tracking with a GMTI radar ground moving targets, the evasive move-stop-move maneuvers of the targets often lead to broken tracks, however, this TSA technique cannot provide satisfactory association performance in stitching this type of broken tracks. Some methods have been proposed to improve the tracking accuracy during the stopped period to reduce broken tracks by using an additional ``stop model'', however, the tracking accuracy in the moving periods may degrade by adding this extra model, which means that, to improve the track performance in the targets' stopped periods, one has to sacrifice some accuracy in the moving periods. The assumption in this paper is that we do not make any change to the original tracking system, e.g. by adding an additional stop model to the tracker (so there will be no performance loss in the moving period). Based on this assumption, we present a new TSA technique which employs a dummy track to formulate a complete association. By using an IMM estimator with state-dependent mode transition probabilities (IMM-SDP) for track segment prediction (forward and backward), the proposed algorithm can effectively stitch both ``regular'' broken tracks and broken tracks due to targets' move-stop-move maneuvers.

7698-13, Session 3

Passive ranging: optimal maneuvers and performance bounds

P. F. Singer, Raytheon Space & Airborne Systems (United States)

The passive ranging equations are derived and conditions on the ownship dynamics, necessary for solution, are inferred. Solutions for range and range rate are then obtained for constant velocity and constant acceleration targets. Expressions for the bias and variance of these estimators of range and range rate are then developed. The resulting set of coupled, nonlinear, ordinary differential equations are solved for the ownship maneuvers which minimizes the range variance for a given range bias. The optimal ownship maneuver in terms of the range and range rate variances is then determined. The Cramer-Rao and Bhattacharyya lower bounds on the range and range rate variances are evaluated.

7698-14, Session 3

CPHD and PHD filters for unknown backgrounds, III: tractable multitarget filtering in dynamic clutter

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

In two previous conference papers I addressed the problem of devising CPHD and PHD filters that are capable of dealing with unknown, dynamically changing clutter backgrounds. The first paper addressed the problem of dynamically estimating the background clutter process, on the fly. The second extended these results to address the problem of multitarget detection and tracking in unknown, dynamically changing clutter. Both papers assumed that the clutter process is Poisson with an intensity function that is a finite mixture with unknown parameters.

In both cases, the measurement-update equations for the CPHD/ PHD filters involve combinatorial sums over all partitions of the current measurement-set. This paper describes an approach that avoids combinatorial sums and is therefore potentially computationally tractable. Clutter is assumed to be a binomial i.i.d. cluster process with unknown parameters. Given this, three different and successively more tractable CPHD/PHD filters are derived, all capable of multitarget track-before-detect capability. The first assumes the entire intensity function of the clutter process is unknown. The second and third assume that the clutter spatial distribution is known but that the clutter rate (number of clutter returns per scan) is unknown.

7698-15, Session 3

Distance and velocity estimation of projectiles based on Doppler radar signals using a nonlinear discrete-time observer

S. Podjawerschek, E. Spahn, Institut Franco-Allemand de Recherches de Saint-Louis (France); M. Brodmann, Univ. of Applied Sciences Gelsenkirchen (Germany); J. Horn, Helmut-Schmidt-Univ. (Germany); R. Himmelsbach, Institut Franco-Allemand de Recherches de Saint-Louis (France)

We propose a new quasi-global observer design to determine the distance and velocity of projectiles e.g. shaped charges or kinetic energy (KE) projectiles in real-time. The detection of the projectile is realized by a low power Doppler radar at short distances (5m-10m). The measured Doppler frequency is the input signal for the observer estimating the states. The advantage of a global observer design is the possibility to deal with large initial errors, which is important because of the usually unknown initial state of the observed system. The transformation to the nonlinear observability canonical form (NOCF) leads to linear error dynamics and this allows a traceable influence on the dynamic behaviour of the observer. This is very useful for the time critical implementation on a real-time system. To benefit from these two advantages, the nonlinear system has to be transformed to the NOCF and an explicit expression of the inverse transformation has to be found. Since this is a very severe restriction for the given application, we propose a numerically approximated inverse transformation in a bounded region of physical interest to allow the design of a quasi-global observer with linear error dynamics for nonlinear discrete-time systems.

The results of this approach are presented using both ideal signals and real Doppler radar signals (shaped charge, KE projectile). The focus is set on stability, transient behaviour for different intrinsic errors and accuracy of the estimation. A discussion of restrictions and an implementation of the observer on a real-time system conclude the paper.

7698-16, Session 3

Homotopy induced spline filter for target tracking

D. L. Kocherry, R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)

In this paper an efficient approach to non-linear non-Gaussian state estimation based on spline filtering is presented. The estimation of the conditional probability density of the unknown state can be ideally achieved using Bayes' rule. However the associated computational requirements make it impossible to implement this online filter optimally in practice. In particle filtering, an efficient way to approximate the Bayes' estimation, estimation accuracy increases with the number of particles at the expense of increased computational load. In this paper, BSpline interpolation is used to represent the density of the state pdf through a low order continuous polynomial. The motivation is to reduce the computational cost.

The motion of spline control points and their coefficients is achieved

using log-homotopy, analogous to the natural time-induced flow as described by the Fokker-Planck equation. The expectation-maximization (EM) algorithm is used to estimate the gradient of the log-homotopy function. This filter is applicable for general state estimation problems as no assumptions are made about the underlying probability density. Finally, simulation results are presented to demonstrate the effectiveness of the proposed algorithm.

7698-17, Session 3

Stabilized flow of particles for nonlinear filters

F. E. Daum, J. Huang, A. Noushin, Raytheon Co. (United States)

We derive a new particle flow to maximize the stability of nonlinear filters. This is a generalization of our particle flow induced by log-homotopy, which used the Moore-Penrose inverse to give a unique minimum norm flow. In this paper we compute the most general solution for particle flow, and we compute the free parameters to maximize stability of the nonlinear filter. This greatly improves the performance of such filters for unstable plants, as well as stable plants with slow mixing (due to low process noise and/or eigenvalues that are marginally stable). In particular, particle filters are generally not stable for unstable plants, in contrast with the Kalman filter, which is guaranteed to be stable under very mild conditions (e.g., controllability and observability of the system model), as proven in Kalman's beautiful paper (1963). That is, the Kalman filter is stable despite the instability of the plant model. Recent attempts to understand the lack of stability for particle filters for unstable plants are surveyed by van Handel (SIAM Conference July 2009). This is a very serious practical problem, because the standard plant models for tracking applications are conditionally unstable. Moreover, the estimation accuracy of particle filters is generally a very strong function of the eigenvalues of the plant model. We solve this important practical problem by optimizing the stability of our filter.

The key idea is to compute Bayes' rule using a flow of particles rather than as a pointwise multiplication. This is analogous to the flow of particles used to model the dynamics of the system in standard particle filters. We do not have to use any proposal density or resampling, because we move the particles to the correct distribution in state space using our particle flow. We completely avoid particle collapse or so-called degeneracy.

The differential equation for classic particle flow (Daum & Huang SPIE Conference 2007) was derived using Liouville's criterion, borrowed from physics. Other ingredients include: the chain rule, the Moore-Penrose inverse and a log-homotopy. It turns out that a homotopy does not work at all, owing to the singularity of the resulting ODE, but a log-homotopy removes the singularity and works extremely well. The most interesting and challenging part of this filter is the approximation of the gradient of the log-homotopy; we studied 17 distinct methods for this, and we now use a simple but effective approach borrowed from geology, combined with a fast approximate k-NN algorithm. This talk is for normal engineers, who do not have log-homotopy for breakfast.

7698-43, Session 3

The GM-CPHD applied to real and realistic multistatic sonar data

R. Georgescu, P. K. Willett, Univ. of Connecticut (United States)

The Cardinalized Probability Hypothesis filter is a recursive filter that propagates both the posterior likelihood of (an unlabeled) target state and the posterior cardinality density (probability mass function of the number of targets). The posterior PHD surface is approximated by a Gaussian Mixture and the weight, mean and covariance of each mode in the mixture are propagated. The GM-CPHD is accompanied by a track management scheme dealing with events such as track initiation, update, merging, spawning and deletion.

The SEABAR07 scientific sea trial featured a deployable multistatic

system (DEMUS) consisting of one source and 3 receiver sonobuoys. The target was an echo repeater towed by a NURC research vessel. Dr. Doug Grimmett adjusted the tagged contacts' SNR of SEABAR07 by injecting aspect-dependent target strength (TS) values, generated from a Basis and a Cylinder model. We present results on the modified A01 and A56 datasets of SEABAR07 and compare them to our results on the original data.

The TNO-Blind dataset was created by Dr. Pascal de Theije and presents the challenge of discovering the number of targets in the interest region and their tracks. We presented our results on this dataset in the 12th International Conference on Information Fusion. Afterwards, the recommended RMS registration error of 0.1sec for the time measurement was revealed to actually be 1.3sec. This change improved our tracker's performance significantly. We show our corrected results and compare them to what was obtained before.

7698-19, Session 4

MLPDA applied to bistatic sonar data sets

S. Schoenecker, Naval Undersea Warfare Ctr. (United States); P. K. Willett, Y. Bar-Shalom, Univ. of Connecticut (United States)

In the early 1990's, the Maximum Likelihood Probabilistic Data Association Filter (MLPDA) was developed in a passive sonar framework, and subsequent research has shown it to be effective for tracking very-low SNR targets. This was done with both active and passive sonar, for targets that have some given deterministic motion. Recent work has focused on applying MLPDA to bistatic sonar data. Here, we apply MLPDA in a sliding and adaptive-length window implementation to three bistatic data sets used by the MSTWG (Multistatic Tracking Working Group): the SEABAR 2007 dataset, the TNO-Blind 2008 dataset, and a new blind dataset provided by Metron in 2009.

A wide filter bandwidth is good in the sense that it offers robustness; however, a large bandwidth allows noise to enter, and in target tracking this noise is usually in the form of clutter. As such, the maximum-likelihood probabilistic data association (MLPDA) estimator - perhaps the ultimate approach to finding targets that are buried deeply in clutter (successful tracking at less than 6dB post-signal processing SNR) - dials the bandwidth as low as it can by searching only for target trajectories that are parametrically defined: for us, that means straight-line trajectories. A multi-target MLPDA was developed by Blanding et al.; our formulation here looks sequentially for single targets, with previously-associated measurements excised, and with the process stopped when a discovered track does not exceed the likelihood threshold.

We find that the MLPDA has no issues at all with deep clutter, and indeed we feel that it may eventually become the algorithm of choice for VLO tracking. Present research on the MLPDA centers on track linkage, and also on means to adapt its parametric modeling of target motion - most suitable for straight-line tracking - to targets such as these that execute structured (but not necessarily straight) trajectories.

7698-20, Session 4

Probabilistic data association in high-clutter environments

R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)

Data association is the key component in single or multiple target tracking algorithms with measurement origin. Probabilistic data association (PDA), in which all the validated measurements are associated probabilistically to the predicted estimate, is one of the well-known methods to handle the measurement origin uncertainty. In PDA, the effect of measurement origin uncertainty is incorporated into the updated covariance by adding the spread of the innovations term. The updated covariance becomes very large after few time steps

in high clutter scenarios due to spread of the innovations term. Large covariance results in a large gate, which is used to limit the possible measurements that could have originated from the target. Hence, the track will be lost and estimate will just follow the prediction. Also, it will make the well-separated target assumption invalid, even if the targets are well-separated. Hence, after a few time steps all the targets in the surveillance region come under the same group and the joint probabilistic data association (JPDA) has to be used. Even the JPDA will result in track coalescence due to large covariance. In this paper, we propose an algorithm to avoid the steady increase in the updated covariance in high clutter. The effectiveness of the proposed algorithm is demonstrated on simulated data.

7698-21, Session 4

Association ambiguity management in mixed-data dimension tracking problems

J. R. Thornbrue, J. Knight, B. Slocumb, Numerica Corp. (United States)

Association and fusion of passive direction finding (DF) reports with active radar tracks from airborne targets is challenging because of the low dimensionality of the common kinematic measurement space. Often, multi-target scenarios lead to significant data association ambiguity. Classically, the approach to this problem is a simple hypothesis test wherein a batch of DF sensor measurements is associated with either zero or one of the radar tracks; assignment of multiple DF tracks to a single radar track is allowed without regard to compatibility, and this can lead to detrimental results. This paper develops a new approach for managing the ambiguity. The problem is formulated as a two-dimensional assignment, and any association ambiguity is determined from the k-best solutions. Firm association decisions are made only when the ambiguity is at an acceptable level. The ambiguity information is also available in real time as an output to the system operator. An improved batch association score, relative to previous works, is formulated that addresses statistical correlations between individual measurement-to-track residuals; this new score is a likelihood ratio generated from Kalman Filter residuals. Where previous scoring methods lead to incorrect ambiguity assessments in certain scenarios, the new approach yields accurate results. Because the score is recursive, the batch may be extended over an arbitrary number of measurements, helping to manage association ambiguities over time. Simulation results will be shown to demonstrate the algorithm.

7698-22, Session 4

Group targets tracking using hypergraph matching for data association

S. Wu, J. Xiao, H. Cheng, H. S. Sawhney, Sarnoff Corp. (United States)

Group moving targets are number of targets independently moving in a physical space but keeping their relative order or pattern invariant. The up to date state-of-art multi-target tracking (MTT) data association methods (GNN,JPDA,MHT) are easily fail on group targets tracking problems, since the track-to-observation ambiguity cannot be resolved if only using the track to observation pair-wised information.

A hypergraph G is represented by G={V, E}, where V is a set of elements called nodes or vertices, E is a set of non-empty subsets containing d-tuple of vertices called hyperedges. It can be used as a new mathematic tool to represent a group of moving targets if we let each target be a vertex and a d-target subset be a hyperedge. Under this representation, this paper reformulates the traditional MTT data association problem as a hypergraph matching one for the hypergraphs formed from both the track and the observation sides, and shows that the traditional approach (only uses the vertex-to-vertex information) is a special case under the proposed framework. In addition to the vertex-to-vertex information, since the hyperedge-to-hyperegde information

is also used in building the assignment/cost matrix, the hypergraph matching based algorithms give better performance than that from the traditional methods in group target tracking problems. We demonstrate this conclusion from simulations as well as video based geotracking examples.

7698-23, Session 4

HCRLB: is it a tighter alternative to CRLB?

X. He, R. Tharmarasa, McMaster Univ. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)

In tracking and estimation problems, the evaluation of the lower bound of the variances of the estimator is of great importance. The achievable bound can be used to test whether an estimator is efficient or not. The most common performance bound in tracking applications is the Cramer-Rao lower bound (CRLB). However, it has been shown that this bound is weak in certain applications. This provides the motivation to find a tighter bound for the variance of estimator in such target tracking problems. The Chapman-Robbins lower bound or Hammersley-Chapman-Robbins lower bound (HCRLB) is another bound for the variance of estimators. It has been proven that the HCRLB is at least equal to and in some cases greater than the CRLB, which means that the HCRLB is expected as a tighter alternative to the CRLB. In fact, HCRLB is a generalization of the Cramer-Rao lower bound. However, in order to apply the HCRLB to real tracking and estimation problem, extensions are necessary, because the original formula of HCRLB can only be applied to static parameter estimation in a clean environment. In this paper, the HCRLB is fully investigated to verify if it is tighter than the CRLB in static parameter estimation scenarios. Then, a more general parameter estimation problem with miss detections and false alarms is considered. Finally, a recursive version of the HCRLB for dynamic state estimation is derived. Simulations are proposed to show the benefits of the HCRLB.

7698-24, Session 4

Using PMHT for separation point estimation

D. T. Dunham, S. E. August, Vectraxx (United States)

Target tracking is limited by the resolution of the sensors providing the measurements. If two objects are in close proximity, they will return just one measurement in most instances. When these two objects separate enough to return two distinct measurements, the question then is where did the objects actually separate? The actual separation point may be of interest and finding that separation point is the topic of this paper. Using the PMHT algorithm allows measurements to be "shared" between tracks, and therefore, makes an excellent algorithm when there are closely-spaced unresolved measurements. In this paper, we will give an overview of how we apply the PMHT algorithm to this separation estimation problem, and then we apply the algorithm to two aircraft flying in formation and then separating. The results are obtained from a high-fidelity simulation environment and provide a good test for this developing approach.

7698-25, Session 4

3D target modeling and activity analysis through target tracking

K. Salva, S. Bischoff, J. R. Vasquez, Numerica Corp. (United States)

Target ambiguity is a major problem in dense urban tracking environments with closely spaced targets. Target classification, action recognition, and 3D feature-aiding can be used to resolve this ambiguity in situations where traditional 2D feature-aiding techniques by themselves are ineffective. An optical flow based algorithm is used in this paper to address the problem of target classification and activity recognition in EO imagery by comparing the optical flow of images over time to a library of image sequences at varying viewing angles. A space-time correlation approach is used to classify targets in IR imagery. The 3D feature-aiding is accomplished through the use of a shape-from-silhouette algorithm that refines a 3D visual hull of a target over time using a bounding edge representation. Knowledge of target location, track state, and sensor orientation can be coupled with these techniques to improve accuracy and tracking performance even further. A combination of synthetic and real data is used to demonstrate these concepts.

7698-26, Session 4

State estimation performance of tracking system with range rate measurements

Y. Zhu, H. Fan, L. Hu, Q. Fu, National Univ. of Defense Technology (China)

Digital signal processing techniques employed in modern radar systems enable the generation of measurements consisting of target 3D position and range rate. However, two crucial issues on range rate measurements utilization remain unresolved, that is, under what conditions and to what extent the performance improvement can be attained by incorporating range rate measurements into the tracking filter. This paper aims to address the two problems. Firstly, the state space models of tracking systems without and with range rate measurements are formulated. Secondly, the lower bounds, i.e., Posterior Cramér-Rao Bounds (PCRBs), for target state estimation errors of the two tracking systems are derived. Thirdly, the primary parameters relevant to the PCRB are discussed, and an effective method for analyzing their effects on state estimation is proposed by comparing the PCRBs of the two tracking systems. Finally, an application example is presented under a typical tracking scenario. The method and results will be of great interest for persons developing tracking system with range rate measurements.

7698-27, Session 5

A no-loss covariance intersection algorithm for track-to-track fusion

X. Tian, Y. Bar-Shalom, Univ. of Connecticut (United States)

One of the most challenging issues for track-to-track fusion (T2TF) in a distributed tracking system is to calculate the exact crosscovariances among the local tracks of the same target, which requires a large amount of information exchange between the fusion center (FC) and the local trackers. For the fusion, depending on the use of memory of the track estimates at the previous fusion time, the information configurations of T2TF include: Track-to-track fusion without memory (T2TFwoM) --- Configuration II, and Track-to-track fusion with memory ---

Configuration II^M [1]. Based on the presence of information feedback the information configurations are further categorized into:

1. T2TFwoM with no information feedback (T2TFwoMnf) --- Configuration II_{nf}

2. T2TFwoM with partial information feedback (T2TFwoMpf) --- Configuration II_{pf}

3. T2TFwoM with full information feedback (T2TFwoMff) --- Configuration II_{ff}

4. T2TFwM with no information feedback (T2TFwMnf) --- Configuration II^M_{nf}

5. T2TFwM with partial information feedback (T2TFwMpf) --- Configuration II^M_{pf}

6. T2TFwM with full information feedback (T2TFwMff) --- Configuration II^M_{ff}

The optimal algorithms (under the linear Gaussian assumption or LMMSE) for the above T2TF configurations are given in [1] for two

trackers. Due to the complexity of calculating the crosscovariances among a large number of local tracks, it is theoretically possible, but practically infeasible, to implement the optimal algorithms when the number of local trackers is large. To circumvent the problem of crosscovariances calculation, the method of covariance intersection(CI) was proposed in the literature and used for T2TFwoMnf. This method does not require the crosscovariances among the local tracks.

However, a significant drawback of the original CI algorithm is that sometimes it is too conservative and will yield unnecessary loss in the calculated fusion accuracy. Even worse, as shown in this paper, the loss in the calculated fusion accuracy increases when the number of local tracks increases. In this paper, a new CI algorithm is proposed, which is simple to implement and does not have the above problematic features of the original CI. Simulation results show that it yields desirable fusion performance for T2TFwoM with all the information feedback configurations.

[1] X. Tian and Y. Bar-Shalom, ``Exact Algorithms for Four Track-To-Track Fusion Configurations: All You Wanted to Know but Were Afraid to Ask," Proc. 12th International Conference on Information Fusion, July 6-9, 2009, Seattle, WA, USA

7698-28, Session 5

Covariance consistency for track initiation using Gauss-Hermite quadrature

J. T. Horwood, N. D. Aragon, A. B. Poore, Numerica Corp. (United States)

The initiation of a consistent state covariance or uncertainty which accurately reflects the discrepancy from truth is a prerequisite to achieving correct data association in tracking. In this paper, the treatment of non-Gaussian states in the initial orbit determination (IOD) or track initiation problem is considered and the accurate and consistent computation of such non-Gaussian uncertainties is addressed. The main contribution is a framework for achieving uncertainty (covariance) consistency in the IOD problem based on efficient Gauss-Hermite quadrature methods. Further, a series of realtime metrics constructed from tensors of higher-order cumulants are proposed which provide a tool for assessing uncertainty consistency. The effectiveness of the proposed IOD method is illustrated through various case studies in space surveillance tracking.

7698-29, Session 5

Scalable self-organizing resource management for multifunction radars in a sensor network

B. S. Weir, The Johns Hopkins Univ. (United States)

Networking radars to form a common air picture has provided a significant leap forward in tracking capability. These advances have existed largely without any capability for coordinating the resources of the networked sensors. In sensor-networking applications, multi-function radars, which have the ability to allocate resources to different radar tasks such as surveillance and tracking, operate largely in a sensor-centric fashion. That is, they make resource decisions based on a local-only tracking capability, and then pass valid measurements to a sensor-networking function that compiles a common air picture. As the list of required missions grows, sensors may no longer be able to operate in such a sensor-centric fashion, and will need to leverage contributions of other networked sensors to meet all performance requirements.

This paper discusses the use of self-organizing principles for managing radar resources in a network-centric fashion. Radars make resource allocation decisions relative to the common, multi-sensor track picture versus a local track picture. By proper construction of the resource

decision rules, the sensors adapt to an efficient global resource allocation using indirect coordination. That is, knowledge of other sensors' contributions to the common air picture is sufficient for the local sensor to apply local resources to tasks where it has a competitive advantage. This approach can offer significant resource savings to the individual sensors and improved tracking performance across the network. Further, the ability to coordinate tracking resources across the network allows for much greater scalability as network size increases.

7698-30, Session 5

Game theoretic approach to collaborative target tracking

G. Chen, DCM Research Resources, LLC (United States); E. P. Blasch, Air Force Research Lab. (United States)

Detecting and tracking an intelligent target from collaborative platforms requires consideration of the targets ability to evade detection from a single and possibly multiple coordinated platforms. The moving target is assumed to be smart, which can escape from the detection by maximizing the estimation error of the assumed constellation of collaborative platforms. If the intelligent target is aware of the collaborative set of platforms and sensors, the target tracking is difficult due to the ability of the target to move outside of sensor coverage. Each platform has a sensor to observe the target and a processor to estimate the target position. We formulate this kind of target tracking problem as a zero-sum game and use a minimax filter to estimate the target position. We also develop a distributed minimax filter for multiple platforms. We will show the feasibility of our proposed approach in a layered sensing scenario that includes a set of platforms (e.g. satellites and UAVs), sensors (e.g. radar and electro-optical), and a variety of target types.

7698-31, Session 5

Likelihood based Track-to-Track Association (T2TA) using rotational motion parameters

R. W. Osborne III, Y. Bar-Shalom, P. K. Willett, Univ. of Connecticut (United States)

In order to carry over information from one sensor to another in a multiple target tracking application---target handover---track-to-track association (T2TA) is necessary. This is very important for applications of ballistic missile defense as the targets will generally be assumed to pass between multiple sensors' surveillance regions over the total target trajectory. Additionally, in ballistic missile defense, the kill vehicle (intercepting missile) will generally have limited time to perform any tracking of the ballistic targets, and information from previous sensors along the target trajectories will aid in providing a successful interception.

The targets will be tracked using traditional techniques to provide the (`point") kinematic data, and the first sensor will be assumed to provide rotational motion data for each target. The rotational motion data (a vector of rotational motion parameters, which can be seen as target features) will be combined with the kinematic data to provide the T2TA between two sensors. The resulting feature-aided T2TA using point kinematics and features is shown to be significantly superior to T2TA using either of these alone.

The rotational motion parameters (features) are estimated at the first sensor, and the T2TA matches these features with the radar cross-section (RCS) variation at the second sensor. In the case of a radar as the second sensor, the measured RCS of each track will be compared to the expected RCS which depends on the estimated features of the tracks from the first sensor. The RCS is modelled as having a Swerling I distribution and this is used in the feaure likelihood function. The second sensor could be an IR sensor, in which case the counterpart of the observed RCS is the target emissivity.

7698-32, Session 5

Network-centric 3D tracking with low-dimensional sensors

N. Coult, R. C. Paffenroth, P. Du Toit, Numerica Corp. (United States)

The coordinated use of multiple distributed sensors by network communication has the potential to substantially improve three-dimensional track state estimates even though each individual sensor might offer only low-dimensional measurements. For example, in the modern electronic warfare environment, hostile electronic countermeasures will endeavor to deny range and range rate information, leaving friendly sensors to depend on passive angle information for tracking. Other sensors may provide only range and bearing but not elevation. Herein we demonstrate algorithms for initiating and maintaining tracks in such operating environments with a focus on efficient representations of non-Gaussian density functions. For example, a Gaussian sum representation can be used for track initiation and track maintenance even when the probability density function representing the state is not Gaussian. Unlike traditional Kalman filtering methods, the accuracy of this approximation may be made as small as desired at the expense of additional computational cost. Non-Gaussian methods such as this are particularly well-suited for non-linear problems with poor observability, where the uncertainty of the state is so large in some directions that the non-linearity becomes a significant factor. This paper discusses the practical issues that must be confronted when implementing such algorithms, including but not limited to the problems of track initiation, forward prediction, and measurement update.

7698-33, Session 5

Multitarget sensor resolution model for arbitrary target numbers

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In many surveillance problems the observed objects are so closely spaced that that they cannot always be resolved by the sensor(s). The resolution may vary in time due to the object group behavior or due to changes in the sensor-object geometry. Typical examples for partially unresolved measurements are the surveillance of aircraft in formation or convoy tracking for ground surveillance.

Ignoring the limited sensor resolution in a tracking system may lead to degraded tracking performance, in particular unwanted track-losses.

The ability of a sensor to resolve several objects can be described by the resolution probability. The corresponding resolution model should approximately cover the essential aspects of the real sensor resolution and should also be mathematically and numerically tractable.

In this paper we extend the resolution model by Koch and van Keuk (IEEE T-AES 33 (3) 1997), given for two partially unresolved objects, to the case of arbitrary object numbers. We also derive the effects of the resolution model to the multi-target likelihood function and the possible data associations. Further, it is shown how the model can be integrated into the Joint Probabilistic Data Association Filter (JPDAF).

7698-34, Session 6

Target tracking with Doppler ambiguity

K. Li, R. Tharmarasa, McMaster Univ. (Canada); M. Pelletier, ICx Radar Systems (Canada); T. Kirubarajan, McMaster Univ. (Canada)

In many radar tracking systems with a certain pulse-repetition frequency (PRF), Doppler (or range rate) measurements may be available in addition to position measurements. Doppler measurements usually improve the tracking performance because of the extra information. However, a fundamental problem associated with Pulse-Doppler radars, especially at low PRFs, is range rate ambiguity. This is because Doppler shifts in the frequency spectrum will be aliased by a difference of an integer times of PRF. In this case, the observed Doppler measurement differs by n*vb from the true range rate of the target, where n is the unknown ambiguity order and vb is the first blind velocity, which depends on the PRF.

In previous works, algorithms to eliminate the Doppler ambiguity based on the Chinese Remainder Theorem have been proposed for radars with multiple PRFs. Time-frequency analysis (TFA) using Fast Fourier Transform (FFT) can reduce the ambiguity in the frequency domain.

In this paper, a new approach for multitarget detection and tracking with Doppler ambiguity is presented. Without the preprocessing of signal to eliminate ambiguity, ambiguous Doppler measurements in addition to the location measurements are directly used in data association and tracking. A new two-dimensional and multiframe assignment solution is proposed to jointly resolve the Doppler ambiguity and data association. In addition, modifications to the Joint Probabilistic Data Association (JPDA) and the Multiple Hypothesis Tracking (MHT) algorithms to resolve Doppler ambiguity are considered. Simulation results are preformed to demonstrate the new algorithms.

7698-35, Session 6

Adaptive tracking and adaptive sensor data fusion

O. E. Drummond, CyberRnD, Inc. (United States)

In the design of a target track processor, specific models and parameters are selected for use in the processing of the sensor data. Some of the parameters may be known and some are not know with certainty so estimates of the values are used. The values of some of the design parameters may be significantly in error and so adjustments are needed. In the field of Kalman filters for example, adaptive methods (sometimes called adaptive filters) have been implemented to estimate in real time (sometimes slowly) more appropriate values for some of the design parameters. While existing adaptive filter methods might be considered for use in estimating some of the parameters in tracking, the possibility of misassociations of measurements to tracks introduces substantial anomalies that may require alternative adaptive methods (possible more complex). Tracking with data from multiple sensors as in sensor data fusion introduces both additional advantages and challenges for adaptive methods relative to single sensor tracking. Fusion also involves functions beyond those typical of tracking and many fusion functions depend on the estimated tracks and/or influence the tracking performance.

To date, most tracker design efforts have been directed to improving the accuracy of the estimated target state using fixed design parameters (and models) and little effort has been directed to real time adaptive processing to the improving the estimates of the design parameters. This paper addresses the degradation in tracker and fusion performance caused by inaccurate design parameters and addresses some considerations for adaptive processing.

7698-36, Session 6

Unified sensor management in unknown, dynamic clutter

R. P. Mahler, Lockheed Martin Maritime Systems & Sensors (United States)

In recent years I have developed a unified, computationally tractable approach to mulisensor-multitarget sensor management. This approach consists of closed-loop recursion of a PHD or CPHD filter with maximization of a "natural" sensor management objective function called PENT (posterior expected number of targets). Like the PHD and CPHD filters, PENT depends on specification of an a priori Poisson false alarm model. A companion paper shows how to extend the PHD and

CPHD filters for operation in unknown, dynamically changing clutter in a computationally tractable manner. In this paper I use those results to derive a formula for PENT so that it can be used in unknown, dynamic clutter. I also show how to extend this formula to a generalized objective function, PENTI (posterior expected number of targets of interest).

7698-37, Session 6

Probabilistic tracking of multiple extended targets using random matrices

M. Wieneke, W. Koch, FGAN-FKIE (Germany)

Conventional tracking algorithms rely on the assumption that the targets under observation are point source objects. However, due to increasing resolution capabilities of modern sensors, the point source assumption is often not suitable and estimating the target extension becomes a crucial aspect. Recently, a Bayesian approach to extended target tracking using random matrices has been proposed. Within this approach, ellipsoidal object extensions are modeled by random matrices and treated as additional state variables to be estimated. However, only a single-target solution has been presented so far. In this work we present the multi-target extension of this approach. We derive a new variant of Probabilistic Multi-Hypothesis Tracking (PMHT) that simultaneously estimates the ellipsoidal shape and the kinematics of each target. For this purpose, the PMHT auxiliary function is extended by random matrices representing the target ellipsoids. Both, the ellipsoids and the kinematic states are iteratively optimized by specific Kalman filter formulae that arise directly from the auxiliary function. The new method is demonstrated and evaluated by simulative examples.

7698-38, Session 6

The JPDAF in practical systems: computation and snake oil

D. F. Crouse, Y. Bar-Shalom, P. K. Willett, Univ. of Connecticut (United States)

In this paper we look at various algorithms for calculating target-measurement association probabilities needed for use in the JPDAF, the JPDAF*, the CJPDAF and the CJPDAF*. We summarize the basic JPDAF algorithm, and review some of the more notable variants thereof.

We show that when rectangular gates are used, the gating problem in tracking is equivalent to the orthogonal range query problem in computer science. Due to the ubiquity of large database systems, many algorithms for performing orthogonal range queries exist. We show that computationally more efficient algorithms, such as the use of range-trees, have been used for many years in database systems and may be applied to tracking systems. We also demonstrate how a simple grouping algorithm may be easily built into a gating algorithm.

We then present a number of exact methods of calculating the target-measurement association probabilities. We review in detail three brute-force techniques for generating the joint association events: a radix search, a depth-first search (a variant that has previously appeared in the literature) and a breadth-first search. The breadth-first search is shown to be the most appropriate association event generation technique when using the JPDAF* and the CJPDAF* algorithms.

We also review a number of approximations for the target-measurement association probabilities and compare their tracking performance to that of the JPDAF through simulation, considering similar past work. Additionally, we single out approximations that are "snake oil" in that their complexity is higher than that of calculating the target-measurement probabilities exactly.

7698-39, Session 6

Assignment-based distributed resource management

A. B. Poore, S. Danford, M. Hilt, Numerica Corp. (United States)

Distributed single and multiple hypothesis (MHT) tracking over multiple platforms connected by a communications network is now well established as robust methodology for achieving a common operational picture and superior tracking as measured by many tracking metrics. In the presence of a large number of objects, the communications network can become overloaded, leading to the need to manage the network communications and sensor resources while maintaining the common operational picture without significant degradation in tracking metrics. In this work, we consider a decentralized resource manager based on a generalized group assignment problem for the assignment of tasks to sensors and demonstrate the reduction in communications and maintenance of SIAP with some preliminary computational results.

7698-40, Session 6

Integration of passive ranging with multiple hypothesis tracking for application with angle-only measurements

S. S. Blackman, Raytheon Space & Airborne Systems (United States); T. White, C. Durand, B. Blyth, Raytheon Co. (United States)

This paper discusses the integration of a passive ranging method that uses multiple initial assumed range bins within a Multiple Hypothesis Tracking(MHT) data association framework. The paper begins with a description of the use of multiple range bins along with a two model Interacting Multiple Model(IMM) approach for tracking potentially maneuvering targets. It discusses the choice of ownship maneuver required to provide observability for an air-to-air encounter.Methods for detecting target maneuver and for choosing subsequent ownship maneuvers to reduce the effects of target maneuver are described. Unscented filtering methods that have been designed for use with the nonlinear angle-only measurements are defined.

Computational feasibility is a major issue with any MHT application and can be particularly important for the typical high false alarm environment envisioned for EO systems,such as the IRST.Thus,the use of multiple range filters is only employed for selected tracks based upon the track score.This and other logic designed to ensure computational feasibility are discussed.Simulation results are presented to illustrate the methods and their performance

7698-41, Session 6

A physics-based approach to nonlinear filters

F. E. Daum, J. Huang, Raytheon Co. (United States)

We compare the accuracy & computational complexity of several nonlinear filters vs. the particle flow filter, including: EKF, UKF, classic PF, auxiliary PF, PFs using proposal densities from the UKF & EKF, etc.

We have invented a new particle filter with vastly superior performance compared with the classic particle filter and the extended Kalman filter. In particular, we achieve estimation errors that are many orders of magnitude smaller than the classic particle filter and several orders of magnitude better than the EKF. Performance of the new filter is also excellent for problems with multimodal densities. We do not use any proposal density, and we do not resample! This is a radical departure from any other particle filter. We evaluate performance for high dimensional fully-coupled (i.e., non-sparse) but smooth problems $(d = 1$ to 24). We have tested five classes of examples, with various nonlinearities, including quadratic and cubic.

The key idea is to compute Bayes' rule using a flow of particles rather
than as a pointwise multiplication. This is analogous to the flow of
particles used to model the dynamics of the system in standard particle
filters. We do not have to use any proposal density or resampling,
because we move the particles to the correct distribution in state space
using our particle flow. We completely avoid particle collapse or so-called
degeneracy. We avoid the curse of dimensionality for certain problems
that enjoy concentration of measure (e.g., log-concave probability
densities). We never compute the density itself, but rather we represent
the unnormalized log-density. Our algorithm is extremely robust, and in
contrast with the EKF, it requires exactly no tuning of parameters. We
show the flow of particles using very interesting movies. In particular,
for an important radar application, we show the correct non-Gaussian
density using our particles, which has been called the "contact lens"
for obvious reasons. For this radar problem, our filter has much better
velocity estimation accuracy compared with the extended Kalman filter.

Conference 7699:
Algorithms for Synthetic Aperture Radar Imagery XVII

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Algorithms for Synthetic Aperture Radar Imagery XVII

7699-01, Session 1

Algorithms for bistatic SAR image formation: polar formatting versus beamforming

C. V. Jakowatz, Jr., D. E. Wahl, D. Yocky, Sandia National Labs. (United States)

The authors have in recent papers discussed SAR image formation via back-projection as derived from a mathematical treatment of phased-array beamforming. The technique has some interesting advantages over traditional methods such as polar formatting, but is disadvantaged in computational speed. In this paper, the beamforming framework is generalized to develop an algorithm for bistatic image formation. The advantages of monostatic beamforming are also realized in bistatic beamforming, but there are interesting features unique to the bistatic modality. Results from real phase history data are shown.

7699-02, Session 1

Doppler synthetic aperture hitchhiker imaging

C. Yarman, Houston Technology Ctr. (United States); L. Wang, Nanjing Univ. of Aeronautics and Astronautics (China); B. Yazici, Rensselaer Polytechnic Institute (United States)

With the growing availability of transmitters of opportunity, such as radio, television and cell phone stations, there has been a growing interest in passive radar applications using sources of opportunity[1-13]. Based on the fact that most of the transmitters of opportunity are single frequency sources, such as radio and TV stations, we consider passive airborne receivers that use backscattered signals from sources of opportunity transmitting fixed-frequency waveforms. Due to its combined passive synthetic aperture and the fixed-frequency nature of the transmitted waveforms, we refer to the system under consideration as Doppler Synthetic Aperture Hitchhiker (DSAH).

We present a novel image formation method for DSAH. Our method first correlates the windowed signal obtained from one receiver with the windowed, filtered, scaled and translated version of the received signal from another receiver. This processing removes the transmitter related variables from the phase of the Fourier integral operator that relates the radiance of the scene and the correlated signal. We, next, use the microlocal analysis[14-17] to reconstruct the scene radiance by the weighted-backprojection of the correlated signal. The analysis of the point spread function (PSF) of the imaging operator shows that this imaging algorithm can put the visible edges of the scene radiance at the correct location, and under appropriate conditions, with correct strength. We show that the resolution of the image is directly related to the length of the support of the windowing function and the frequency of the transmitted waveform. The final image of the scene radiance is formed by averaging over the images obtained for each pair of receivers at each time translation. We present numerical experiments to validate the theoretical analysis and demonstrate the performance of the proposed method.

Our passive imaging method has the following advantages:

(1) as compared to the existing passive radar detection/imaging systems[1-12], it does not require receivers with high directivity; (2) it can be used in the presence of both cooperative and non-cooperative sources of opportunity; (3) it can be used with multiple stationary sources of opportunity; (4) it can be used with one or more airborne receivers. (5) it is an analytic reconstruction technique which can be made computationally efficient.

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7699-03, Session 1

Tutorial on Fourier space coverage for scattering experiments, with application to SAR

R. W. Deming, Air Force Research Lab. (United States)

The Fourier Diffraction Theorem (e.g., [1]) relates the data measured during radar, optical, or acoustic scattering experiments to the spatial

Fourier transform of the object under test. The theorem is well-known, but since the typical derivation is based on integral equations and expansions for the Green's function, it may be difficult to understand for the non-specialist. In this paper, the theorem is derived and presented using simple geometry, plus undergraduate-level physics and mathematics.

For practitioners of radar tomography and SAR imaging, the Fourier Diffraction Theorem is important to understand because it leads to a simple geometric and graphical understanding of the Fourier coverage resulting from particular data collection geometries and bandwidths. The greater the extent of the coverage in Fourier space, the sharper the resulting point spread function in physical (x,y,z) space. Sometimes a given measurement geometry will result in odd-looking and incomplete Fourier coverage [1,2] which, if thoroughly understood, can be augmented and "filled in" with additional experiments. Also, once the data samples are mapped to their corresponding points in Fourier space, reconstruction can be performed simply by interpolating, then applying the inverse Fourier Transform [3].

The paper will discuss several practical examples, including stripmap SAR and multi-bistatic inverse-scattering. An interesting case will be presented in which gaps (nulls) in the radar bandwidth are precisely compensated for by careful placement of an additional receiver. All results will be based upon simulated data.

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7699-04, Session 1

Dual format algorithm for monostatic SAR

L. Gorham, Air Force Research Lab. (United States); B. D. Rigling, Wright State Univ. (United States)

No abstract available

7699-05, Session 1

SAR image formation toolbox for MATLAB

L. Gorham, L. J. Moore, Air Force Research Lab. (United States)

No abstract available

7699-06, Session 1

An analytical expression for the three-dimensional response of a point scatterer for circular synthetic aperture radar

L. J. Moore, Air Force Research Lab. (United States) and Univ. of Dayton (United States); U. Majumder, Air Force Research Lab. (United States)

Three-dimensional spotlight-mode Synthetic Aperture Radar (SAR) images of point scatterers provide intuition regarding the achievable effectiveness of automatic target recognition (ATR) algorithms given a variety of operating parameters such as elevation angle, azimuth or aperture extent, frequency bandwidth and location of the target with respect to the scene center. Of particular interest is the circular SAR scenario given 360 degrees azimuth, motivated by the benefits of persistent surveillance and the potential for 3-D image reconstruction improvement compared with limited aperture SAR due in part to the increase in favorable viewing angles of unknown targets. The response of a point scatter at the origin, or center of the target scene, is known and has been quantified for circular SAR in previous literature by a closed-form solution. The behavior of a point scatterer radially displaced from the origin has been previously characterized for circular SAR through implementation of backprojection image reconstructions. In this manuscript, we derive a closed-form expression for the response of an arbitrarily located point scatterer within the scene for a circular SAR aperture of 360 degrees. Thus, the response of a scatterer residing at the origin represents a special case of the solution provided in this work. Analysis of the characteristics of such a response indicates the role of target persistence or employed aperture extent in successful detection and identification of targets located on or off the scene center.

7699-07, Session 1

An analysis of 3D SAR for sub-Nyquist nonlinear radar platform trajectories

D. B. Andre, Defence Science and Technology Lab. (United Kingdom)

This paper presents an analysis of 3-D SAR image formation under the challenging condition of sub-Nyquist sampling in the elevation dimension. The analysis is operationally relevant as it is often not possible for a radar platform to collect radar data at sufficient grazing angles to satisfy the Nyquist sampling criterion. For example, under certain conditions only a single pass data collection will be feasible.

It is found that to a certain extent, these sampling issues can be overcome through the use of non-linear radar platform trajectories. In conventional 2-D SAR imaging this approach can be viewed as detrimental as the image depth of focus is reduced, however for 3-D imaging a reduced depth of focus has been found to be advantageous.

The approach however, comes at the cost of resultant unusual image point spread functions, with reduced resolution in the vertical dimension. It is possible to obtain a wide range of point spread functions as a function of collection parameters including range, the form of the non-linear radar platform trajectories and centre frequency. This work explores this parameter space to find advantageous radar collection geometries.

Resultant image point spread functions can be difficult to characterise analytically, so a numerical approach has been undertaken utilizing both point and flat plate scatterer simulations.

Example 3-D SAR images are presented utilizing the Backhoe radar Data Dome DARPA challenge problem dataset.

7699-32, Session 1

Autofocus for 3D imaging with multipass SAR

N. C. Boss, E. Ertin, R. Moses, The Ohio State Univ. (United States)

No abstract available

7699-08, Session 2

Superresolution inverse synthetic aperture radar (ISAR) imaging using compressive sampling

S. K. Gunnala, S. Tjuatja, The Univ. of Texas at Arlington (United States)

Classical ISAR images are limited in resolution. Both down range resolution and cross range resolutions of the ISAR images are limited in practice due to finite bandwidth and unavailability of larger angular sector over which target is observed. To date there are several super-resolution algorithms which are computationally intensive and require extrapolation

of information outside the measurement aperture. In this paper, a method based on compressive sampling to achieve super-resolution in ISAR imaging is presented.

The proposed super-resolution ISAR imaging estimates the target's signal subspace from the measured signal space by exploiting the sparsity of the targets' scattering centers in the image domain. The sparsity of target's signal satisfies the restricted isometric property (RIP) condition as required by compressive sampling for accurate recovery of signal from its compressed samples. The super-resolution ISAR imaging algorithm is implemented by enforcing the sparsity constraints via random compressive sampling of the measured data. Sparsity constraint ratio (SCR) is used as a design parameter. Mutual coherence is used as quantitative measure to determine the optimal SCR. ISAR data from controlled laboratory measurements for full angular sector as well as different partial angular sectors are utilized in this study to validate the proposed approach. Results show that significant resolution enhancement is achieved at SCR in the 20% range. More details about the super-resolution ISAR imaging and results of different measured data sets will be presented in the full paper.

7699-09, Session 2

Bayesian SAR imaging

Z. Chen, X. Tan, M. Xue, J. Li, Univ. of Florida (United States)

We introduce a maximum a posteriori (MAP) algorithm and a regularized minimization (RM) algorithm to synthetic aperture radar (SAR) imaging application for good sidelobe suppression and high image resolution. Both MAP and RM are sparse signal recovery algorithms. The former cyclically maximizes the a posteriori probability density function for a given sparsity promoting prior, while the latter cyclically minimizes a regularized least squares cost function. We show how MAP and RM can be adapted to the SAR imaging application and used to enhance the image quality. We evaluate the performance of MAP and RM using the complex backscattered data from a backhoe vehicle. The experimental results show that both MAP and RM satisfactorily suppress the sidelobes and yield higher resolution. MAP and RM outperform the widely used CoSaMP algorithm, which requires the delicate choice of one user parameter representing the signal sparsity. Compared with the recently developed iterative adaptive approach (IAA), MAP and RM are computationally more efficient, especially with the help of 2-D fast Fourier transform (2-D FFT).

7699-10, Session 2

Experimental validation of a microwave tomographic approach for through-the-wall radar imaging

F. Soldovieri, Instituto per il Rilevamento Elettromagnetico dell'Ambiente (Italy); R. Solimene, Seconda Univ. degli Studi di Napoli (Italy); F. Ahmad, Villanova Univ. (United States)

Through-the-wall radar imaging (TWRI) is an emerging research area of increasing interest as the objective of detection and localization of obscured targets is shared by many defense and civilian applications. TWRI is a difficult problem, which requires the development of innovative data processing approaches that are able to deal effectively with the challenges arising from the presence of the wall and the complexity of the scene. We consider a microwave tomographic approach, which is based on the solution of a linear inverse scattering problem and incorporates the effect of the wall via the Green's function in a simple and accurate way [1]. The inversion is made stable through a regularization scheme based on truncated-singular value decomposition (TSVD). The emphasis of the paper will be on the validation of the microwave tomographic approach using experimental data collected in a semi-controlled laboratory environment. Both simple and complex through-the-wall scene layouts will be considered.

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7699-11, Session 2

Contourlet domain hidden Markov tree-based detection algorithm for DRDC through-wall synthetic aperture radar system (TWSAR) applications

B. Chan, Defence Research and Development Canada (Canada)

DRDC Ottawa is investigating high resolution synthetic aperture radar (SAR) techniques to perform 3-D imaging through walls in urban operations. Through-wall capabilities of interest include room mapping, imaging of in-wall structures, and detection of objects of interest. Such capabilities would greatly enhance situational awareness for military forces operating in the urban battle space. Current activities include hardware and software development and testing of an L-band through-wall SAR (TWSAR) system. Detection algorithms and automatic target recognition (ATR) systems are under investigation using experimental 2-D data.

ATR may be much more difficult in an urban environment due to the high number of detectable objects and multi-path artifacts. Furthermore, penetrating through walls presents a formidable challenge as wall affects can greatly interfere with image quality inside buildings. By classifying wall material, wall compensation algorithms can be applied to enhance the image. In this paper, we present results from our preliminary investigation on detecting internal and external wall structures and their features (including doors and windows as well as internal wall construction) from scenes acquired with a single channel L-band TWSAR system. We evaluate the effectiveness of automatic detection based on the contourlet domain hidden Markov tree in the context of detecting wall edges and building features, while minimizing the amount of false edge detection. This work will form the basis of wall compensation algorithm development. The detection technique will also be used to detect objects of interests beyond walls once the SAR images have been wall compensated.

7699-12, Session 2

A videoSAR mode for the x-band wideband experimental airborne radar

A. Damini, B. Balaji, C. M. Parry, Defence Research and Development Canada (Canada); V. Mantle, MacDonald, Dettwiler & Associates Ltd. (Canada)

No abstract available

7699-13, Session 2

Desch: supercomputer for real-time wide-area SAR data exploitation

U. Majumder, M. J. Minardi, M. G. Judge, L. Gorham, S. M. Scarborough, C. H. Casteel, Jr., J. Carter, E. Bracy, Air Force Research Lab. (United States); T. L. Klein, Mission Research Corp. (United States); L. Spoldi, A. Pieramico, Technology Service Corp. (United States)

No abstract available

7699-14, Session 2

SAR GIS data analysis on the iPhone

U. Majumder, Air Force Research Lab. (United States); R. J. Vickery, High Performance Technologies, Inc. (United States)

We created an iPhone application that loads SAR imagery and allows the user to interact with it. The user multi-touch interface provides pan and zoom capabilities as well as options to change parameters relating to the query. Information relating to the region of interest is displayed for additional drill-down analysis. We describe how operatives in the field can use this application to investigate SAR and GIS related problems on the iPhone mobile device, which otherwise would require a computer and Internet connection.

7699-15, Session 3

SAR-based adaptive GMTI

D. Vu, B. Guo, L. Xu, J. Li, Univ. of Florida (United States)

Spotlight-mode synthetic aperture radar (SAR) can provide significantly improved azimuth resolution when imaging a restricted spot by coherently processing multiple pulses from different azimuth angles. Multiple-input multiple-output (MIMO) SAR based ground moving target indication (GMTI) can utilize the high resolution provided by SAR to discriminate small moving targets from the background clutter while exploiting the MIMO advantage to increase the virtual aperture for improved GMTI. MIMO SAR offers the advantage of reduced cost, weight and size as compared to the conventional single-input multiple-output (SIMO) SAR. Due to the limited focal area of spotlight-mode SAR, the duration of the transmitted waveforms can be much longer than the maximum round-trip time delay between the nearest and farthest range bins of the focal area. This means that we only need to synthesize waveforms with good auto- and cross-correlation properties within a limited time delay interval, i.e., waveforms with zero correlation zones. The recently proposed weighted cyclic algorithm -- new (WeCAN) approach and the periodic cyclic algorithm (PeCA) can be used to synthesize unimodular sequences with zero auto-correlation sidelobes and zero cross-correlations within the zero correlation zone. The SIMO SAR based GMTI is a special case of its MIMO SAR based counterpart, and the former is currently under investigation as one of the challenges of the Air Force Research Laboratory (AFRL). We will consider adaptive algorithms for GMTI using both MIMO and SIMO SAR. We will evaluate the performance of the SAR based GMTI using simulated data for MIMO SAR and using the experimental data provided by AFRL for SIMO SAR.

7699-16, Session 3

Moving target detection with SAR

G. E. Newstadt, Univ. of Michigan (United States); E. G. Zelnio, L. Gorham, Air Force Research Lab. (United States); A. O. Hero III, Univ. of Michigan (United States)

A unique approach for moving target detection with synthetic aperture radar (SAR) is proposed based on using known road structures to model the movement of targets within small zones/regions of interest. In general, moving targets cause phase errors in the reconstruction of a SAR image that can result in smearing and/or displacement of the targets trajectory. Jao (2001) developed equations to predict the target's migration path given both the platform and target trajectories. This work derives the posterior density of the moving target's location within a SAR image, given priors on a single target's trajectory. Detection statistics based on this posterior density are also derived. Future work plans to verify this work against both simulated data and the SPIE challenge data set for SAR-based GMTI in urban environments.

7699-17, Session 3

Limits to focusing accuracy for moving passenger vehicles in circular synthetic aperture radar

A. Fasih, R. L. Moses, The Ohio State Univ. (United States)

[Awaiting public release from AFRL]

7699-18, Session 3

Verification of target motion effects on SAR imagery using the Gotcha GMTI challenge dataset

D. E. Hack, M. A. Saville, Air Force Institute of Technology (United States)

A primary goal of persistent surveillance systems is the tracking of ground moving targets such as automobiles and dismounts. An obstacle to tracking with staring SAR systems is the complicated interplay between target motion and image effects such as cross-range offset, defocus, and smearing. In addition to complicating the detection process, such effects also introduce ambiguity into the geolocation and measurement-to-track association processes, both requisite for tracking.

This paper investigates the relationship between a ground moving target's kinematic state and its SAR image. While this topic has been studied previously by a number of authors, including Raney (1971), Jao (2001), and Ruegg (2005), such studies have typically employed simplifications such as constraining target motion to the imaging/slant planes, assuming constant velocity/acceleration over the coherent processing interval, and assuming ideal point scattering targets. Such simplifications raise questions about applicability to more realistic scenarios.

This study focuses on experimental verification of previously derived motion effects using the Gotcha GMTI challenge dataset. This dataset provides an ideal opportunity for verification as it contains radar and target GPS truth, allowing comparison between theoretically predicted and actual imaging effects. Furthermore, it contains realistic phenomena such as non-ideal radar trajectories, target motion out of the nominal ground plane, non-uniform target velocity/acceleration, and extended targets. A comparison of predicted and actual imaging effects in the presence of such phenomena provides insight into the extent to which realistic operating conditions limit or weaken the applicability of previously derived results.

7699-19, Session 3

Estimation of vibration spectra including vibrating direction with synthetic aperture radar

M. Pepin, M. M. Hayat, The Univ. of New Mexico (United States)

This paper develops a method for characterizing vibrating objects measured with Synthetic Aperture Radar (SAR). It has been shown that objects vibrating during a SAR measurement produce a phase modulation in the returned radar signal. Using the validated model for this vibration return the vibration spectrum (frequencies, and amplitudes or displacements) and the planar direction of vibration can be estimated directly from the phase history data of the vibrating object along the cross range. This vibration signal, however, is perturbed by the SAR data-collection process, which samples the vibration signal non-uniformly in angle producing a non-uniform amplitude envelope in the phase modulation, which produces a vibration-direction dependent modulation of the frequencies in the vibration spectrum. Independent estimation of the vibration spectrum and vibration direction of the perturbed data can result in large estimation errors; thus, the vibration parameters must

be estimated in conjunction with the changing observation angle to correctly characterize the vibration. In this paper, a novel employment of the damped exponential model using a robust method available to estimate the model with high fidelity is used to simultaneously estimate the vibration parameters and the directional envelope. Two variations of this approach are developed and the methods are tested with simulated data to verify their performance and to determine the conditions required for good estimates. It is shown that the method produces good vibration spectrum and vibration direction estimates when at least one and a half vibration cycles are present in the data.

7699-34, Session 3

Analysis of focused dismount signatures

T. L. Lewis, Air Force Research Lab. (United States); B. D. Rigling, Wright State Univ. (United States)

No abstract available

7699-20, Session 4

A comparison of spatial sampling techniques enabling first-principles modeling of a synthetic aperture radar imaging platform

M. G. Gartley, Rochester Institute of Technology (United States); R. P. Kauffman, Lockheed Martin Management & Data Systems (United States); S. D. Brown, A. A. Goodenough, Rochester Institute of Technology (United States)

Simulation of synthetic aperture radar (SAR) imagery may be approached in many different ways. One method treats a scene as a radar cross section (RCS) map and simply evaluates the radar equation, convolved with a system impulse response to generate simulated SAR imagery. Another approach treats a scene as a series of primitive geometric shapes, for which a closed form solution for the RCS exists (such as boxes, spheres and cylinders), and sums their contribution at the antenna level by again solving the radar equation. We present a ray-tracing approach to SAR image simulation that treats a scene as a series of arbitrarily shaped facetized objects, each facet potentially having a unique radio frequency optical property and time-varying location and orientation. A particle based approach, as compared to a wave based approach, presents a challenge for maintaining coherency of sampled scene points between pulses allowing for reconstruction of an exploitable image from the modeled complex phase history. We present a series of spatial sampling techniques and their relative success at producing accurate phase history data for simulations of spotlight, stripmap and SAR-GMTI collection scenarios.

7699-21, Session 4

Comparison of real and simulated SAR imagery of ships for use in ATR

N. Ødegaard, Norwegian Defense Research Establishment (Norway); A. O. Knapskog, Norwegian Defence Research Establishment (Norway); C. Cochin, Direction générale de l'armement (France)

Collecting real data to build a database for automatic target recognition (ATR) in SAR imagery can be an overwhelming task. Simulated SAR images of targets are therefore desirable. To use simulations for ATR, however, one has to make sure they are similar enough to real SAR images. This paper will investigate the similarity of SAR images of ships simulated with MOCEM to real data of the same targets collected with TerraSAR-X and PicoSAR. MOCEM is a SAR image simulation tool that generates a SAR image from a CAD model in a short time. The tool

calculates the major scattering mechanisms on the target based on the geometry of the scene and the electromagnetic properties of the materials chosen for the object. Subsequently a SAR transfer function, corresponding to the radar parameters selected by the user, is applied to the geometrical image. We have looked at how materials must be modeled and applied to different parts of the object in order to produce a realistic simulation. The level of detail in the CAD model will also influence the similarity of the real and simulated image, and we have studied which details on the ships must be modeled, and which are less important. If the estimated aspect angle of the target deviates too much from the correct one, SAR images will start to de-correlate. This paper will present an investigation of what effect the aspect angle estimate has on the correlation between real and simulated SAR images.

7699-22, Session 4

Civilian vehicle radar data domes

K. E. Dungan, C. Austin, The Ohio State Univ. (United States); J. Nehrbass, High-Performance Technologies, Inc. (United States); L. C. Potter, The Ohio State Univ. (United States)

We present a set of simulated X-band scattering data for civilian vehicles. For ten facet models of civilian vehicles, a high-frequency electromagnetic simulation produced fully polarized, far-field, monostatic scattering for 360 degrees azimuth and elevation angles from 30 to 60 degrees. The 369 GB of phase history data is stored in a Matlab file format. This paper describes the details of generating the data along with example imagery using 2D backprojection, single pass 3D, and multipass 3D.

7699-23, Session 4

Classifying sets of attributed scattering centers using a hash coded database

K. E. Dungan, L. Potter, The Ohio State Univ. (United States)

No abstract available

7699-24, Session 4

Application of sparse dictionaries to SAR speckle reduction

T. R. Braun, J. B. Greer, National Geospatial-Intelligence Agency (United States)

Synthetic Aperture Radar (SAR) provides day/night all weather imagery, and as such is being increasingly utilized for overhead reconnaissance. Additionally, the active, coherent nature of the system provides for analysis not readily achievable with electro-optical imagery. However, like all coherent systems, SAR imagery suffers degradation from speckle (a random interference pattern) which hinders interpretation. Herein, we investigate SAR denoising with a new method based on sparse reconstruction over learned dictionaries and show this approach performs better than the current state of the art speckle filters.

7699-25, Session 4

Target detection in SAR images using codifference and directional filters

K. Duman, A. E. Cetin, Bilkent Univ. (Turkey)

Unlike infrared or optical sensors, synthetic aperture radar (SAR) sensors are able to produce the images of terrains under any weather conditions at any time of day and night. Automatic detection and recognition of

man-made (metal) objects in SAR images have been an active research area in recent years [1, 2].

In this paper, a pre-processing stage based on directional filtering is introduced for the target detection and classification in SAR images using the region covariance (RC) algorithm proposed in [3]. Directional wavelet filters were successfully used as a first stage in many applications including vector quantization and image coding [4-8]. Regions of interests (ROIs) in SAR images which are simply determined based on the amplitude information are filtered using two-dimensional Haar-wavelet type filters in order to classify both the target and clutter (non-target) images into categories according to their orientations.

The output of the pre-proccessing stage is fed to a detection stage in which representative feature parameters are extracted using covariance and codifference matrices of the ROIs. An advantage of using covariance and codifference matrices is their small dimension compared to the size of ROIs. In addition, the speckle noise in SAR images is reduced by the natural averaging operation during the computation of these matrices. These matrices are used as feature space parameters for support vector machines (SVM) for discrimination between target and clutter images in each directional class. It is experimentally observed that the directional approach reduces the computational complexity without decreasing the target detection accuracy in publicly available Moving and Stationary Target Recognition (MSTAR) database. Target detection and false alarm rates are comparable to the method in [3] which has high computational cost. When 8 different directional Haar filters are used in pre-processing stage and the ROIs are represented using co-difference matrices, the target detection rate is 2630/2651 (99.21%) and the false alarm rate is 90/13445 (0.669%).

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7699-26, Session 4

Diversity detection in non-Gaussian noise employing the generalized approach to signal processing with fading diversity channels

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

In this paper, we consider the problem of M-ary signal detection based on the generalized approach to signal processing in noise over a single-input multiple-output channel affected by frequency-dispersive Rayleigh distributed fading and corrupted by additive non-Gaussian noise, modeled as spherically invariant random process. We derive both the optimum generalized detector structure and a suboptimal, reduced-complexity generalized detector applying the low-energy-coherence approach jointly with the generalized approach to signal processing in noise. Both generalized detector structure are canonical, i.e., they

are independent of the actual noise statistics. We also carry out a performance analysis of both generalized receivers and compare with the conventional ones. The performance analysis is carried out with reference to the case that the channel is affected by a frequency-selective fading and for a binary frequency-shift keying signaling format. The results obtained through both a Chernoff-bounding technique and Monte Carlo simulations reveal that the adoption of diversity also represents a suitable means to restore performance in the presence of dispersive fading and impulsive non-Gaussian noise. It is also shown that the suboptimal generalized receiver incurs a limited loss with respect to the optimum generalized detector and this loss is less in comparison with the conventional receiver.

7699-27, Session 4

Challenge problem for SAR change detection and phase history compression

S. M. Scarborough, L. Gorham, M. G. Judge, M. J. Minardi, U. Majumder, L. J. Moore, Air Force Research Lab. (United States)

No abstract available

7699-28, Session 4

Classification of canonical scattering through subband analysis

D. Fuller, M. A. Saville, Air Force Institute of Technology (United States)

The spectrum parted linked image test (SPLIT) algorithm was experimentally shown to estimate frequency-dependency of dominant scattering centers through sub-band analysis. Based on its demonstrated potential for classifying canonical scatterers, a theoretical model of the SPLIT algorithm is presented in this paper. Terms are defined, procedures are detailed, and a metric for total least squares model fitting is developed. In addition, the paper addresses multiple observations, measures of confidence, sidelobe interference and sensitivity to bandwidth and noise. Finally, it is described how the one-dimensional (1D) SPLIT algorithm can be extended for use with 2D and 3D imaging.

7699-29, Session 4

Synthetic aperture radar parameter-based model for predicating image quality

A. J. Terzuoli, Jr., J. E. McGowan, Air Force Institute of Technology (United States)

Synthetic Aperture Radar (SAR) produces high quality images from great distances with day/night and all-weather capabilities. While there has been work done to create an image-based model for SAR images, such as the National Imagery Interpretation Rating Scale (NIIRS), there are no widely used parameter-based models that can provide a predictable performance level for image quality. A widely used parameter-based model for EO and IR images is the General Image Quality Equation (GIQE) which predicts NIIRS level. This research shows how SAR image properties relate to GIQE parameters. SAR image properties are broken into system properties and scene properties. First the system properties are tested by varying the impulse response of the system. The varying of the system parameters, the pulse bandwidth and the aperture length, affect the spatial resolution and the edge response of the image. A sample image is created with a single point target per image pixel. To test scene properties simple metal targets such as cylinders, corners and plates are simulated showing how different shapes can affect image quality. Next more complex simulated targets are used which leads to the ability of a system to separate features on targets. This research leads to a connection to the GIQE for SAR but it also shows how the system

parameters affect the ability to detect features of targets allowing for greater understanding in the ability to identify targets of interest.

7699-30, Session 4

Depth-based image registration

B. Han, C. Paulson, J. Wang, D. O. Wu, Univ. of Florida (United States)

Computer vision is playing more and more important role in modern science and technology. Image registration is a fundamental task in computer vision because it can greatly contribute to high-level computer vision and benefit numerous practical applications. Though a lot of image registration techniques exist in the literature, this problem is far from being solved perfectly due to the parallax problem. The traditional image registration algorithms cannot solve parallax problem due to their underling assumption that the scene can be regarded approximately planar which is not satisfied any more in the case of large depth variation in the images with high-rise objects. With regard to the above challenging problem, a new strategy is proposed by leveraging the depth information via 3D reconstruction. One novel idea is to recover the depth in the image region with high-rise objects to build accurate transform function. Our method overcomes this weakness and can achieve robust registration results, which is validated by our experiments. Our algorithm is attractive to tremendous practical applications.

7699-33, Session 4

FOPEN change detection experiments using a CARABAS public release data set

L. M. Novak, Scientific Systems Co., Inc. (United States)

No abstract available

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Conference 7700: Enabling Photonics Technologies for Defense, Security, and Aerospace Applications VI

Monday-Tuesday 5-6 April 2010 • Part of Proceedings of SPIE Vol. 7700 Enabling Photonics Technologies for Defense, Security, and Aerospace Applications VI

7700-01, Session 1

Underwater multiview three-dimensional imaging with passive sensing

B. Javidi, R. T. Schulein, M. Cho, Univ. of Connecticut (United States)

In this Keynote Address paper, the authors present an overview of their research on under water 3D imaging using passive sensing. Experimental results, theoretical analysis, applications, and various imaging modalties are provided.

7700-02, Session 2

Pattern recognition of electronic bit sequences using a semiconductor mode-locked laser and spatial light modulators

S. P. Bhooplapur, M. Akbulut, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); F. J. Quinlan, National Institute of Standards and Technology (United States); P. J. Delfyett, Jr., CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A novel scheme for recognition of electronic bit-sequences is demonstrated. The two bit-sequences to be compared are each mapped to a unique code from an orthogonal code set. The orthogonal codes are then phase encoded in parallel on the frequency comb lines from a frequency-stabilized mode-locked semiconductor laser using two independent spatial light modulators. Coherent Pulse Detection is used for matching of the orthogonal codes, thereby allowing recognition of arbitrary bit-sequences with high accuracy. This technique has potential for high-speed, high accuracy recognition of bit-sequences, with potential applications in data mining and information security.

7700-03, Session 2

Multi-heterodyne mixing of frequency stabilized combs for ultrafast coherent signal processing

J. Davila-Rodriguez, M. Akbulut, C. G. Williams, P. J. Delfyett, Jr., CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Fast and precise measurements of ultrafast optical waveforms are essential to the development of optical coherent signal processing. In this paper, multi-heterodyne mixing of stabilized optical frequency combs is presented as a simple technique for the measurement of ultrafast laser pulses and exotic arbitrary optical waveforms. This technique takes advantage of both the broadband nature of the frequency comb and the narrow line-width of the individual comb-lines to produce an array of radio-frequency beat-notes that share the characteristics of the optical spectrum. Measurements of comb characteristics across THz of bandwidth are enabled by this method, while maintaining the accuracy at the level of the individual comb-line width. Results show that both frequency modulation and amplitude modulation combs can be measured using this scheme.

7700-04, Session 2

Secure optical communication based on optical domain encryption and coherent detection

X. Li, G. Li, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

A secure optical communication scheme is proposed based on optical domain encryption and coherent detection. The measure of security is investigated and secure transmission of quadrature phase-shift keying signal is demonstrated experimentally.

7700-05, Session 2

Nonlinearity compensation for Raman-amplified optical transmission systems

L. Zhu, E. Mateo, G. Li, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Electronic dispersion compensation in combination with coherent detection has been used to increase the transmission distance by eliminating any additional loss associated with the optical dispersion compensation modules. Recently, a scheme of electronic impairment compensation was proposed, where dispersion and nonlinearity in WDM transmission were compensated via split-step backward propagation. In this paper, impairment compensation for fiber transmission with Raman amplification is simulated. The system with impairment compensation is different from the reported system with electronic dispersion compensation in the method of digital signal processing (DSP). The simulation results show that the impairment compensation significantly increases the transmission distance at the expense of acceptable computational requirement.

7700-06, Session 2

Scalable transceiver architecture for space and airborne applications

P. S. Guilfoyle, S. Mahnkopf, M. Harris, D. Louderback, T. Eustis, V. Koleva, D. Kumar, OptiComp Corp. (United States); R. L. Kaminski, Air Force Research Lab. (United States)

A multimode transceiver architecture is presented that transmits and receives multiple wavelengths over a single fiber or strand of fibers. The receiver and transmitter optical subassemblies couple the emission to and from a generally two-dimensional array of high speed photodetectors and VCSELs, respectively. Unique multiplexing and demultiplexing techniques enable operation over extended temperature ranges using multimode VCSEL sources. Each VCSEL is directly modulated at 10.7 Gbps resulting in aggregate data rates that can be scaled from 40 Gbps for transmission of 4 wavelengths over a single fiber to 1.44 Tbps for transmission of 12 wavelengths over each of 12 fibers.

7700-07, Session 2

Improved microwave photonic link performance through optical carrier suppression and balanced coherent heterodyne detection

C. F. Middleton IV, R. DeSalvo, Harris Corp. (United States)

The insertion of microwave photonic links in traditional microwave communication systems presents many advantages, such as increased bandwidth, immunity to electromagnetic interference, reduction of size and weight, and frequency-independent loss over long distances. But microwave photonic links often lack the gain, noise figure and dynamic range performance required to replace traditional microwave links. We present a microwave photonic link architecture that enables high gain and dynamic range, low noise figure, and multi-octave bandwidth operation. Our method uses double sideband suppressed carrier modulation together with a balanced coherent heterodyne detection scheme. The modulation method increases link linearity by producing carrier-suppressed amplitude modulation based on the optical field rather than intensity. The combination of carrier suppression, optical amplification, phase-locked local oscillator insertion, and balanced detection provide high signal-efficient gain, reduced intermodulation distortion, wide-band operation, frequency agile spectrum access, and low link noise.

7700-08, Session 2

Techniques to maintain functionality during degraded performance

J. R. McCoy, Everis Inc. (United States)

In this paper the authors present their work that has fundamentally enabled an enterprise to insure operational viability under the very real cyber facts; "we are under constant attack, it is a hostile space and we can control the point of contact". That point of contact is the optical bit stream that is currently beyond the scope of the standard cyber tool set. Everis, working with our customers, has developed the tools to view, capture, analyze and control the correlative (interdependent network, metadata, data and users) information as it transverses the core regional and global fiber optic networks. This capability to "see" below the operational picture afforded by current network intrusion detection systems combined with realtime intervention at the network core yields prioritization, identification, authentication of authentication that directly translates into sophisticated end user interaction across the interdependencies often viewed as a "cloud". Everis has demonstrated unique applications based on this paradigm shift capability that includes mitigation of DDOS, identification of network entry point independent of IP address, optical path fail over and wan IPs.

7700-09, Session 3

Air Force Highly Integrated Photonics program: development and demonstration of an optically transparent fiber optic network for avionics applications

G. J. Whaley, R. Karnopp, Lockheed Martin Maritime Systems & Sensors (United States)

The goal of the Air Force Highly Integrated Photonics (HIP) program is to develop and demonstrate single photonic chip components which support a single mode fiber network architecture for use on mobile military platforms. We propose an optically transparent, broadcast and select fiber optic network as the next generation interconnect on avionics platforms. In support of this network, we have developed three principal, single-chip photonic components: a tunable laser transmitter, a 32x32 port star coupler, and a 32 port multi-channel receiver which are all compatible with demanding avionics environmental and size requirements. The performance of the developed components will be presented as well as the results of a demonstration system which integrates the components into a functional network representative of the form factor used in advanced avionics computing and signal processing applications.

7700-10, Session 3

Hybrid planar lightwave circuits for defense and aerospace applications

M. R. T. Pearson, S. Bidnyk, A. Balakrishnan, Enablence (Canada)

Planar Lightwave Circuits (PLCs) have gained widespread acceptance in telecommunications, and are now viewed as an enabling technology to reduce the size and cost of components for aerospace and defense, while improving reliability and functionality. We discuss PLCs that contain no moving parts, pose no spark or fire hazard, are extremely small and lightweight, and are capable of transporting and processing optical signals with exceptionally high performance. This PLC platform is designed for on-chip integration of active components such as lasers and detectors, along with amplifiers and other electronics. These active components are hybridly integrated with our silica-on-silicon PLCs using fully-automated robotics and image recognition technology. This PLC approach has been successfully applied to the design and fabrication of multi-channel transceivers for aerospace applications. The chips contain hybrid DFB lasers and high-efficiency detectors, each capable of running over 10 Gb/s, with mixed digital and analog traffic multiplexed to a single optical fiber. This highly-integrated functionality is combined onto a silicon chip smaller than 4 x 10 mm, weighing < 5 grams. These chip-based transceivers have been measured to withstand harsh g-forces, including sinusoidal vibrations with amplitude of 20 g acceleration, followed by mechanical shock of 500 g acceleration. The components operate over a wide range of temperatures, with no device failures after extreme temperature cycling through a range of > 125 degC, and more than 2,000 hours operating at 95 degC ambient air temperature. We believe that these recent advancements in PLCs are poised to revolutionize optical communications and interconnects in the aerospace and defense industries.

7700-11, Session 3

Photonics enabled layer 2-switch fabric for UAV and satellite applications

P. S. Guilfoyle, T. Eustis, S. Rathjen, OptiComp Corp. (United States); R. L. Kaminski, Air Force Research Lab. (United States)

A novel OSI Layer 2 switch fabric is presented, designed for the high bandwidth digital signal processing needs of UAVs and satellites. Only with photonic based transceivers can the high speed data rated required in emerging digital signal processing application be achieved. Thus the switch fabric, built on the RapidIO standard, was designed with plans to utilize OptiComp's 1x4lambda 40Gbps transceiver. The fabric design facilitates low latency, fault tolerance, while being highly configurable for multiple CONOPS. Continued convergence of the high-end signal processing community on the RapidIO, re-enforces its selection for these applications.

7700-12, Session 3

Characterization of data transmission through a maritime free-space optical channel with a custom bit error rate tester

J. E. Sluz, J. L. Riggins II, J. C. Juarez, C. Nelson, R. M. Sova, D. W. Young, The Johns Hopkins Univ. (United States)

Free Space Optical Communications channels can exhibit high percentage availability, yet are subject to frequent fades due to turbulence effects. At gigabit per second rates, tremendous amounts of data can still be transported through a fading channel, but an efficient network protocol is required to overcome the effects of fades. We describe a custom error detector that can process a signal from a channel which has frequent fades below system sensitivity and can provide data link statistics with bit-level timing accuracy. The statistics can be used to develop efficient network protocols over the measured channel.

The test system described in this paper provides a data stream at a rate between 0.6-6.25 Gbps. In order to manage the statistics at gigabit per second speeds, data processing was performed real time within a Field Programmable Gate Array (FPGA). Summary results can be polled at a rate as short as 25 ms. These statistics include bit level counters which allow the device to be used as a traditional BERT, as well as block-based counters, which provide insight to the channel for packet based transmission formats. Synchronization parameters are adjustable to accommodate different link dynamics. Stretched error and sync pulse outputs also provide useful live indicators of link performance when plotted against optical channel power.

This paper will discuss the performance of the cBERT in testing a 2.5 Gbps channel over a maritime FSO link trial conducted off the mid-Atlantic coast near Wallops Island, VA, in July and September 2009. Additionally, the overall design of the cBERT will be presented.

7700-13, Session 3

A MIMO-based optical phased array laser radar system

H. Zmuda, N. S. Sharma, Univ. of Florida (United States)

This paper will address the analysis, design, and implementation of an electronically scanned phased array laser radar (ladar) system utilizing the techniques of multi-input multi-output (MIMO) array design. MIMO radar is has attracted much attention recently from both researchers and practitioners alike due to its significant potential for advancing the state-of-the-art in radar technology. The laser radar architecture presented stands to have significant impact on the ability to apply RF array processing methods to laser radar systems in several ways. Specifically, using MIMO array design concepts, it is shown that the resolution of the ladar array can substantially exceed the diffraction limited resolution of a conventional array. Additionally, the use of array methods provides the capability to electronically steer the aperture, thus avoiding the mechanical beam scanning methods generally encountered in laser radar systems. Finally, by using an array of radiators, an increase in total radiated power is achieved, significantly relieving the power burden on a single laser. The problems traditionally encountered in applying conventional array techniques to laser/detector arrays, for example, the inability to achieve half-wavelength spacing or the surfacing of source coherence issues, actually work to one's advantage when viewed in the MIMO paradigm. It is anticipated that the successful implementation of this system will significantly advance the state-of-the-art of laser radar capabilities for imaging, target detection, tracking, and signature analysis.

7700-14, Session 4

Self-focusing effects in gain-guided fibers

R. Zhou, Univ. of Dayton (United States); B. Ibarra-Escamilla, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); Q. Zhan, P. E. Powers, J. W. Haus, Univ. of Dayton (United States)

We simulate propagation of spatio-temporal pulses in large-nmode area gain-guided (GG) fibers using a beam propagation method with diffraction effects included in the simulations. The effect of third-order nonlinearity, i.e. self-phase modulation, is reported on pulse amplitude and phase.

In a two-dimensional geometry the third-order nonlinearity leads to the self-focusing and collapse of the beam into a filament, unless the collapse is arrested by other processes. At the same time, the nonlinear index induced spatial dispersion leads to an additional temporal dispersion for the pulse. The numerical modeling of propagation is performed with different GG fiber parameters and applictions to mode-locked fiber lasers is reported.

7700-15, Session 4

Group delay measurement of 1.3-μm quantum dot semiconductor optical amplifier over 120 nm of spectral bandwidth

M. Bagnell, J. Davila-Rodriguez, A. Ardey, P. J. Delfyett, Jr., CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The broad gain bandwidth of quantum dot devices has potential for creation of extremely short optical pulses. Careful management of intracavity dispersion is necessary to make full use of the gain spectrum. This work presents group delay and group delay dispersion data for a quantum dot semiconductor optical amplifier in the wavelength range of 1200 to 1320 nm, covering both ground state and first excited state transitions, under various injection currents. White-light interferometry was used to obtain dispersion data. Group delay dispersion values at the ground and first excited state peaks were found to be 8.4 fs/nm and 4.5 fs/nm respectively and largely independent of injection current.

7700-16, Session 4

Terahertz frequency generation in optical amplifiers

E. J. Donkor, Univ. of Connecticut (United States)

We describe the generation of terahertz optical frequency comb using the spontaneous emissions from a semiconductor optical amplifier as the signal source. The source drives an all-fiber LYOT-Sagnac birefringent fiber. This transforms the broad band source into a discrete set of evenly spaced frequencies. The output of the Sagnac loop mirror is then coupled to fiber pigtailed Faraday Mirror reflecting the optical frequency comb back into the optical amplifier for further amplification. The method resulted in generating optical frequency comb ranging from 183THz to 213 THz with frequency spacing of 560 GHz.

7700-17, Session 5

Recent advances in semiconductor-based optical frequency comb generation and coherent signal processing applications

P. J. Delfyett, Jr., CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No abstract available

7700-18, Session 6

Time-domain parabolic pulse creation of ultrafast chirped pulse

D. T. Nguyen, CREOL, The College of Optics and Photonics. Univ. of Central Florida (United States)

Parabolic pulse generation in time domain was experimentally demonstrated. Near transform limited pulses with gaussian-shape optical

spectrum generated by a Mode-Locked Laser (MLL) are dispersed using a Chirped Fiber Bragg Grating. The time profile of the dispersed pulses will match the optical spectrum of the laser, due to frequency-to-time mapping resulting from the linear chirp. A simple amplitude modulator is used, where the driving electrical signal is quasi-static and is calculated to incorporate the optical spectral shape, the modulator's nonlinear response and the desired parabolic pulse shape. Preliminary result of pulse shaping with MLL source is presented. Parabolic pulse generation using a CW laser source was also demonstrated.

7700-19, Session 6

Cylindrically polarized fiber laser

R. Zhou, Univ. of Dayton (United States); B. Ibarra-Escamilla, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico); Q. Zhan, P. E. Powers, J. W. Haus, Univ. of Dayton (United States)

Radially and azimuthally polarized beams are solutions to Maxwell's equations which obey rotational symmetry in both polarization and field amplitude. Due to their unique properties, these so-called cylindrical vector (CV) beams are finding a wide range of applications.

Fiber lasers have attracted increasing interests owing to their relatively high gain, compactness and flexibility. Recently, various kinds of fiber laser designs have been explored to produce CV beams. The basic underline principle is to use appropriate elements in the cavity to select the desired polarization. The use of intracavity devices such as dual conical prism, axicon, and spatially variable retarder have been demonstrated. However, these methods require the use of elements that are either difficult to fabricate or not suitable to support high power.

We introduce a simple and efficient design to generate both radial and azimuthally polarized beams using a c-cut calcite crystal with a three-lens telescope in an erbium-doped fiber laser cavity. We report the generation of CV beams without the hard aperture stop, and for the first time, the capability of switching between radial and azimuthal polarization output in a simple manner. A maximum power of 140 mW has been obtained, which is much higher than the previously reported output powers from fiber lasers generating CV beam outputs.

7700-20, Session 6

Cubic Zn$_x$Mg$_{1-x}$O and Ni$_y$Mg$_{1-y}$O thin films grown by molecular beam epitaxy for deep-UV optoelectronic applications

J. W. Mares, R. C. Boutwell III, A. Scheurer, W. V. Schoenfeld, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Oxide semiconductor compounds have been of increasing interest for wide bandgap, deep ultraviolet (DUV) optoelectronics. While high Al content AlGaN has enabled many UV-DUV technologies, it suffers inherent drawbacks including difficulty achieving large Al incorporation, high threading dislocation densities and challenges in bandgap engineering due to polarization and piezoelectric fields. Here we present our pioneering work on two wide bandgap cubic oxide compounds, ZnMgO and NiMgO, that offer an alternative new route to DUV devices. Ni$_y$Mg$_{1-y}$O and Zn$_x$Mg$_{1-x}$O (x<0.5) are both direct band gap, cubic rocksalt (B1) semiconductors with close lattice matching to MgO substrates and bandgaps in the UV-DUV spectral region.

We will present our work on the growth of Zn$_x$Mg$_{1-x}$O and Ni$_y$Mg$_{1-y}$O thin films by plasma-assisted MBE on lattice matched MgO substrates. Results demonstrating bandgap tunability and excellent thin film quality will be discussed. Ni$_y$Mg$_{1-y}$O films were varied compositionally from y=0 to 1, exhibiting bandgaps from 3.5 to 7.8 eV. Zn$_x$Mg$_{1-x}$O films were similarly varied over the entire cubic phase of the ternary (0<x<0.42) showing bandgap tunability from ~5 to 7.8 eV. Initial MSM detectors have been successfully fabricated from both ternary alloys, demonstrating

operation in the solar blind regions without the need for external filters. Initial efforts to extrinsically dope the compounds will be discussed along with first attempts towards heterojunction structures comprised of the two ternaries.

7700-21, Session 6

Motivation and approach to creating true color temperature low-light-level V-NIR source

S. D. Scopatz, J. A. Mazzetta, F. A. Ennerson, Electro Optical Industries, Inc. (United States)

With the continuing innovation in night vision and multispectral imaging technologies, the requirements for more sophisticated test systems continue to increase. Various manufacturers of Visible and Near Infrared (V-NIR) cameras and detection systems need to verify the lowest detectable light level and check system performance at very low light levels as well as recovery from exposure to typical daytime light levels. Typical low level requirements are in the range of 10^-4 to 10^-6 foot-lamberts, equivalent to starlight radiance levels; typical daytime light levels are 10^3 foot-lamberts. There is a relatively straightforward approach to producing low light level output using "neutral" density filters to reduce the light to the proper level. The neutral density filters are not spectrally neutral over the entire V-NIR wavelength range. For some test applications the loss of spectral fidelity is unacceptable for tests of sensor response. The challenge was to create an adjustable output V-NIR source that maintains the color temperature setting over the entire output range. This paper explains how the requirement of True Color Temperature Low Light Level source is met and the benefits compared to prior methods. In addition how the daylight level is also met with the same source. Once the high and low light levels are achieved in a stable and repeatable manner and are calibrated; the unique tests that can be performed with this source are discussed.

7700-22, Session 6

Disturbance of visual functions as a result of temporary blinding from low-power lasers

H. Reidenbach, Fachhochschule Köln (Germany)

Two different test set-ups were designed and applied in order to determine the afterimage duration and the recovery time for visual acuity after temporary blinding from a laser, respectively.

In order to get the desired information a helium-neon laser was mounted on a movable assembly where the respective beam position and direction could be set up on a semicircle. The power was adjusted in several steps in order to investigate the respective dependence of the afterimage. The trials have been done with several volunteers in the laboratory.

Besides a maximum of 300 s the dose relationship t/s = 50.6 x ln[(P x texp)/µJ] - 13.4 for laser output powers P between 10 µW and 30 µW with exposure durations texp from 0.25 s up to 10 s was found. The inability to read due to the disturbance produced by afterimages lasts for about 20 s even if the exposure is not more than 0.25 s from a laser with about 0.8 mW.

Instead of the standard visual acuity measurement used by eye care professionals, a reading test on a computer monitor was applied after laser irradiation. In this case two different laser were used as a dazzling light source, one with a wavelength of 632.8 nm and the other with 532 nm. The maximum applied optical power in a 7-mm aperture, which is equivalent to the pupil diameter of a dark adapted eye, was 0.783 mW. The exposure durations were chosen as 0.25 s, 0.5 s, 1 s, 5 s, and 20 s.

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7701-01, Session 1

Ship detection in satellite imagery using rank-order grayscale hit-or-miss transforms

N. R. Harvey, R. B. Porter, J. Theiler, Los Alamos National Lab. (United States)

Ship detection from satellite imagery is something that has great utility in various communities. Knowing where ships are and their types, provides useful intelligence information. However, detecting and recognizing ships is a difficult problem. Existing techniques suffer from too many false-alarms. We describe approaches we have taken in trying to build ship detection algorithms that have reduced false alarms. Our approach uses a version of the grayscale morphological Hit-or-Miss transform. While this is well known and used in its standard form, we use a version in which we use a rank-order selection for the dilation and erosion parts of the transform, instead of the standard maximum and minimum operators. This provides some slack in the fitting that the algorithm employs and provide a method for tuning the algorithm's performance for particular detection problems. We will describe our algorithms, techniques for finding the optimal rank-order parameter and illustrate the use of this approach for real ship detection problems with panchromatic satellite imagery.

7701-02, Session 1

Joint image deblurring, segmentation, and spectral trace recovery for material identification using variational methods

R. J. Plemmons, Wake Forest Univ. (United States); F. Li, East China Normal Univ. (China); M. K. Ng, Hong Kong Baptist Univ. (Hong Kong, China); Q. Zhang, Wake Forest Univ. (United States); S. Prasad, The Univ. of New Mexico (United States)

A crucial aspect of spectral image analysis is the identification of the materials present in the object or scene being imaged and to quantify their abundance in the mixture. An increasingly useful approach to extracting such underlying structure is to employ image classification and object identification techniques to compressively represent the original data cubes by a set of spatially orthogonal bases and a set of spectral signatures. Important enabling technologies include image enhancement, segmentation and resulting dimension reduction, and spectral trace recovery. In particular, since multi-spectral or hyperspectral imagery is generally low resolution, it is possible for one pixel in the image to contain several materials due to blurring across pixels. Also, effective dimension reduction by segmentation and classification into segments whose pixels have common spectral traces is also an important consideration, and noise and blur can present significant data analysis problems. In this paper, we describe a variational fuzzy segmentation model coupled with a denoising/deblurring model based on fast total variation regularized computations. We show the efficiency of this new strategy on hyperspectral images associated with space object material identification, and on HYDICE and related remote sensing images. For the space object identification application, these variational appraches are compared with the tensor-based methods described in the paper [Tensor Methods for Hyperspectral Data Analysis: A Space Object Material Identification Study. Q. Zhang, H. Wang, R. Plemmons and P. Pauca. Vol. 25, No. 12, J. Optical Soc. Amer. A, Dec. 2008].

7701-03, Session 1

Automatic scene modeling for improving object classification

S. Foucher, M. Lalonde, L. Gagnon, CRIM (Canada)

In video surveillance, automatic methods for scene understanding and modelling can exploit the high redundancy of object trajectories observed over a long period of time. The goal of scene understanding is to generate a semantic model of the scene describing the patterns of normal activities. We are proposing to boost the performances of a real time object tracker in terms of object classification based on the accumulation of statistics over time. Based on the object shape, an initial three classes object classification (Car, Pedestrian and Other) is performed by the tracker. This initial labelling is usually very noisy because of object occlusions/merging and the eventual presence of shadows. The proposed scene modelling approach is derived from Makris's algorithm where the scene is described in terms of clusters of similar tracks (called routes). The original envelope based model is replaced by a simpler statistical model around each route's node. The resulting scene model is then used to improve object classification based on the statistics observed within the node population of each route. Finally, the Dempster-Shafer theory is used to fuse multiple evidence sources and compute an improved object classification map. In addition, we investigate the automatic detection of problematic image areas that are the source of poor quality trajectories (object reflections in buildings, trees, flags, etc.). The algorithm was extensively tested using a live camera in a urban environment.

7701-04, Session 1

Detection of moving objects from a moving platform in urban scenes

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Moving object detection in urban scenes is important for the guidance of autonomous vehicles, robot navigation, and monitoring.

In this paper moving objects are automatically detected using three sequential frames and tracked over a longer period. To this extend we modify the plane+parallax, fundamental matrix, and trifocal tensor algorithms to operate on three sequential frames automatically, and test their ability to detect moving objects in challenging urban scenes. Frame-to-frame correspondences are established with the use of SIFT keys. The keys that are consistently matched over three frames are used by the algorithms to distinguish between static objects and moving objects. The tracking of keys for the detected moving objects increases their reliability over time, which is quantified by our results. To evaluate the three different algorithms, we manually segment the moving objects in real world data and report the fraction of true positives versus false positives.

Results show that the plane+parallax method performs very well on our datasets and we prove that our modification to this method outperforms the original method. The proposed combination of the advanced plane+parallax method with the trifocal tensor method improves on the moving object detection and their tracking for one of the four video sequences.

7701-05, Session 1

Human detection in MOUT scenarios using covariance descriptors

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Military Operations in Urban Terrain (MOUT) require the capability to perceive and to analyse the situation around a patrol in order to recognize potential threats. Such situations are known to be stressful for human operators and thus intelligent assistance systems are wanted. As in MOUT scenarios threats usually arise from humans one important task is the robust detection of humans.

Detection of humans in MOUT by image processing systems can be very challenging, e.g., due to complex outdoor scenes where humans have a weak contrast against the background or are partially covered by objects or each other. Porikli et al. introduced covariance matrices as human descriptors - so-called covariance descriptors - and showed their usefulness for human detection in complex scenes. Based on this technique we developed a new method for the classification of covariance descriptors which improves the human detection accuracy.

We describe our human detection method and evaluate the detector on benchmark data sets generated from real-world image sequences captured during MOUT exercises.

7701-06, Session 1

A two-stage approach to detect abandoned baggage in public places

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Baggage abandoned in public places can pose a serious security threat. In this paper a two-stage approach that works on video sequences captured by a single immovable CCTV camera is presented. At first, foreground objects are segregated from static background objects using brightness and chromaticity distortion parameters estimated in the RGB colour space. The algorithm then locks on to binary blobs that are static and of `bag' sizes; the size constraints used in the scheme are chosen based on empirical data. Parts of the background frame and current frames covered by a locked mask are then tracked using a 1-D (unwrapped) pattern generated using a bi-variate frequency distribution in the rg chromaticity space. Another approach that uses edge maps instead of patterns generated using the fragile colour information is discussed. In this approach the pixels that are part(s) of edge(s) are marked using a novel scheme that utilizes four 1-D Laplacian kernels; tracking is done by calculating the total entropy in the intensity images (current frames) in the sections encompassed by the binary edge maps (masks). This makes the process broadly illumination invariant. Both the algorithms have been tested on the iLIDS dataset, and the results obtained are encouraging.

7701-07, Session 2

Visual contrast enhancement and measurement techniques applied to optical coherence tomography

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Optical coherence tomography (OCT) is an interferometric, noninvasive and non contact imaging technique that image biological tissues at micrometer scale resolution. Raw images obtained from the OCT process are often corrupted with noise and suffer low visual contrast levels. This paper focuses on improving the visual contrast of OCT images using combined digital enhancement and fusion techniques. Since OCT images are often corrupted with noise, effective noise-reduction algorithms followed by series of digital enhancement techniques that are suitable for the OCT images are used. We also investigate any gain in visual contrast if combined enhancement is employed. In the image fusion methods, images taken at different OCT depths are fused together using discrete wavelet transform. Any gain in visual contrast enhancement will be justified using contrast measurement techniques.

7701-08, Session 2

A multi-algorithm-based automatic person identification system

M. M. Monwar, M. Gavrilova, Univ. of Calgary (Canada)

Multimodal biometrics is an emerging area of research that aims at increasing the reliability of biometric systems through utilizing more than one biometric in decision-making process. Systems using information from multiple biometric cues can be multi sensor based, multi algorithm based, multi instance based, multi sample based and multimodal based. But an effective fusion scheme is necessary for combining information from various sources. Such information can be integrated at several distinct levels, such as sensor level, feature level, match score level, rank level and decision level. In this work, we develop a multi algorithm based multibiometric system utilizing face and ear features and rank and decision fusion approach. We use multilayer perceptron network and fisherimage approach for monomodal recognition. For the first approach, we use holistic face and ear features for recognition and employ pixel minimization techniques for computational speed up. For the second approach, we use PCA (Principal Component Analysis) and FLDA (Fisher's Linear Discriminant Analysis), which gives us very good recognition performance based on intra-class variations. After individual face and ear recognition, we integrate the results of the two face matcher using rank level fusion approach. We experiment with Borda count method, Borda fuse method and Markov chain method of rank level fusion approach. Due to the better recognition performance we employ Markov chain approach for combined face decision. Similarly, we get combined ear decision. These two decisions are combined for final recognition decision. We try with 'AND'/'OR' rule, majority voting rule, weighted majority voting rule and behavioural knowledge space rule of decision fusion approach. From the experiment results, we find that weighted majority voting rule works better than any other decision fusion approaches and hence, we incorporate this fusion approach for the final recognition decision. The final results indicate that using multi algorithm based can certainly improve the recognition performance of biometric systems. This system can be effectively used in law enforcement or homeland security department or for commercial purposes.

7701-09, Session 2

Issues and challenges in the development of a commercialised image fusion system

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Image fusion technology is becoming increasingly used within military systems. However, the migration of the technology to non-defence applications has been limited, both in terms of functionality and processing performance. In this paper, the development of a low-cost automatic registration and adaptive image fusion system is described. In order to fully exploit commercially available processor hardware, an alternative registration and image fusion approach has been developed and the results of this are presented. Additionally, the software design offers interface flexibility and user programmability and these features are illustrated through a number of different applications.

7701-12, Session 3

Wavefront phase mask design, fabrication, and analysis for improved iris recognition imaging

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Wavefront phase encoding has recently been proposed and explored

as a technique for extending the depth of field of standard limited-focus imaging systems, and consequently the user-to-camera distance range of iris recognition imaging. We report on the design and fabrication of a wavefront phase mask for extending the iris recognition operating range of a F/# 2.3 imaging system from 2 to 10 inches. The phase mask was designed using pupil phase engineering methods previously reported in the literature. We model and analyze the performance of this phase mask using computer simulations and contrast the simulation results with actual imagery obtained in the lab. Our results confirm the viability of using pupil phase engineering for phase mask design, we discuss the pros and cons of wavefront phase modulation, and emphasize the need for computational imaging in task specific problems such as biometric iris recognition.

7701-13, Session 3

Comparing FPGAs and GPUs for high-performance image processing applications

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Modern image enhancement techniques have been shown to be effective in improving the quality of imagery. However, the computational requirements of applying such algorithms to streams of video in real-time often cannot be satisfied by standard microprocessor-based systems. While a scaled solution involving clusters of microprocessors may provide the necessary arithmetic capacity, deployment is limited to data-center scenarios. What is needed is a way to perform these techniques in real time on embedded platforms. A new paradigm of computing utilizing special-purpose commodity hardware including Field-Programmable Gate Arrays (FPGAs) and Graphics Processing Units (GPU) has recently emerged as an alternative to parallel computing using clusters of traditional CPUs. Recent research has shown that for many applications, such as image processing techniques requiring intense computations and large memory spaces, these hardware platforms significantly outperform microprocessors. Furthermore, while microprocessor technology has begun to stagnate, GPUs and FPGAs have continued to improve exponentially. FPGAs, flexible and powerful, are best targeted at embedded, low-power systems and specific applications. GPUs, cheap and readily available, are available to most users through their standard desktop machines. Additionally, as fabrication scale continues to shrink, heat and power consumption issues typically limiting GPU deployment to high-end desktop workstations are becoming less of a factor. The ability to include these devices in embedded environments opens up entire new application domains. In this paper, we investigate two state-of-the-art image processing techniques, super-resolution and the average-bispectrum speckle method, and compare FPGA and GPU implementations in terms of performance, development effort, cost, deployment options, and platform flexibility.

7701-14, Session 3

Computationally efficient radar image-based forecasting using RBF neural networks

D. Charalampidis, S. Kattekola, Univ. of New Orleans (United States)

Radial Basis Function neural networks (RBFNN) have been used for tracking of storm fronts in weather imagery. The RBFNN approach assumes that precipitation can be modeled as a combination of localized envelopes, whose shape, position, and intensity changes in time. Forecasting can be achieved by tracking of all localized envelopes comprising the large scale precipitation events. Recently, the authors proposed an alternative RBFNN-based approach for the purpose of modeling precipitation in weather imagery in a computationally efficient manner. The main argument supporting the importance of computational efficiency is that short-term forecasting would be ineffectual if the time for which forecasting is performed was as far in the future as the time required for predicting the path of precipitation events. Initial

experimentation had illustrated that the proposed technique is capable of successfully modeling rain events in radar imagery, and thus present a more efficient alternative to the original RBFNN technique. However, no significant experimentation was performed to determine if the proposed technique presented a trade-off between efficiency and forecasting effectiveness. In this work, the effectiveness of the proposed modeling technique for forecasting purposes is studied and compared to previous technique. It will be shown that although the proposed technique is several orders faster, it is still as capable of successfully tracking rain events as previous techniques.

7701-11, Poster Session

The max white effect on the Retinex white-balancing algorithm

A. M. T. A. Elmesalami, NARSS (Egypt)

The proposed white-balancing approach (CMW-Retinex) combines the two traditional algorithms: Max white and Single Scale Retinex (SSR) in an attempt to enhance the faded colors of the input images. A set of the quadratic equations, similar to those introduced in [1, 2] are used to perform the mapping. The proposed approach is developed to combine the strengths of the two founding algorithms. Therefore, it assumes that the intensities of the green channel never change; yet, all changes are introduced to the red and blue channels. Two quadratic equations are used to perform the corrections and to compensate for the poor performance associated with the linear mapping of the Retinex and MW techniques. The two equations are adequate to achieve some satisfactory color corrections for the human observers. However, in order to enhance the performance of the proposed technique, we should also fulfill the requirements of the two founding algorithms MW and Retinex, which is explained with more details in the final papers. The Gaussian elimination and the Cramer's rule are the most suitable methods to solve the provided equations for the mapping and color correction constants.

Experimental results are provided to test the performance of the proposed color restoration approach. Evaluation of the results is assessed by the human observation for the input and output images. Also, a mathematical metric (cast measurements of the input and output images) is utilized for a numerical evaluation of the results. Some color enhancements can be observed in some regions of the output images, which emphasize the impact of the Max white on the single scale Retinex white-balancing algorithm. The results also show some of the negative impact of the MW on the single scale Retinex in specific limited regions of the output images, especially the bright regions.

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7701-32, Poster Session

An effective background subtraction under the mixture of multiple varying illuminations

Y. Guo, Y. Ming, Beijing Univ. of Posts and Telecommunications (China)

Background subtraction is an effective method in detecting moving objects in a static scene, which requires a fixed camera, and a static background. Illumination changing is a challenging problem which causes

failure of background subtraction. Most background subtract algorithms require the illumination changing slowly, so the object can be tracked accurately and the background is easy to update. If the illumination changes rapidly and nonmonotonously, many algorithms fail. In this paper, we do some research on the condition when there are multiple lights which simulate continuously and rapidly varying illuminations. This kind of condition has many applicable scenes in daily life. This scene can be seen not only in doors or in the dark or in underground architecture but also out doors or in the light. We propose a new algorithm based on the illumination factor which can be applied to not only the indoor environment but also outdoors with natural illumination. In our algorithm, illumination factor is computed through the comparison of background and the current frame. The background is estimated and updated based on this factor, which tracks the change of background accurately and reduces the chance of failure. Experiments have proven the effectiveness of our method.

7701-33, Poster Session

A novel online learning method for head detection in video sequences

D. Luo, Huazhong Univ. of Science and Technology (China); N. Sang, Huazhong Univ. of Science and Technology (China) and Wuhan Polytechnic Univ. (China); R. Huang, Huazhong Univ. of Science and Technology (China); X. Tong, Wuhan Polytechnic Univ. (China)

Online learning is an effective incremental learning method. Compare with the conventional off-line learning method, online learning updates the original classifier continuously with new samples and improves its performance. In this paper, we propose a novel online learning framework for head detection in video sequences. At first, an off-line classifier is trained with a few labeled samples. And it was used to object detection in video sequences. Based on online boosting algorithm, the detected objects will be used to train the classifier as new samples. Instead of using another detection algorithm to label the new sample automatically like other online learning framework, we ensure the correct label from tracking. Furthermore, the weights of new samples can be obtained from tracking directly. Thus the training speed of the classifier can be improved. Experimental results on two video datasets are provided to show the efficient and high detection rate of the framework.

7701-34, Poster Session

Improve online boosting algorithm from self-learning cascade classifier

D. Luo, Huazhong Univ. of Science and Technology (China); N. Sang, Huazhong Univ. of Science and Technology (China) and Wuhan Polytechnic Univ. (China); R. Huang, Huazhong Univ. of Science and Technology (China); X. Tong, Wuhan Polytechnic Univ. (China)

Online boosting algorithm has been used in many vision-related applications, such as object detection. However, in order to obtain good detection result, combining a large number of weak classifiers into a strong classifier is required. And those weak classifiers must be updated and improved online. So the training and detection speed will be reduced inevitably. This paper proposes a novel online boosting based learning method, called self-learning cascade classifier. Cascade decision strategy is integrated with the online boosting procedure. The resulting system contains enough number of weak classifiers while keeping computation cost low. The cascade structure is learned and updated online. And the structure complexity can be increased adaptively when detection task is more difficult. Moreover, most of new samples are labeled by tracking automatically. This can greatly reduce the effort by labeler. We present experimental results that demonstrate the efficient and high detection rate of the method.

7701-36, Poster Session

Real-time implementation of turbulent and imaging degradations deconvolution

B. Zuo, J. Tian, Huazhong Univ. of Science and Technology (China)

A real-time deconvolution algorithm is presented for the restoration of the images which are degraded by the atmospheric turbulence and imaging. The considering imaging degradations include a variety of factors: uncontrolled platform or scene jitter, optical system aberrations and instabilities, noise characteristic of the detector. This paper proposes a fast blocking deconvolution algorithm for recovering images by using total variation (TV) regularizations in mixed l1-l2 norm. The algorithm could avoid produce any blocking or ringing artifacts due to a rigid block structure. So the algorithm could be efficiently parallelized and implemented on the parallel hardware platforms. The algorithm uses an alternating minimization scheme in which the main computation involves shrinkage and a few fast Fourier transforms (FFT), or alternatively discrete cosine transforms (DCT) when the hardware has good performance on DCT. Furthermore, an algorithm is proposed to optimize the convergence rate of the deconvolution algorithm. Finally, the parallel hardware platform experiments verify the effectiveness of the deconvolution algorithm.

7701-37, Poster Session

Enhancing low-contrast image by separately processing illuminance and reflectance

R. Huang, Huazhong Univ. of Science and Technology (China); N. Sang, Huazhong Univ. of Science and Technology (China) and Wuhan Polytechnic Univ. (China); D. Luo, Huazhong Univ. of Science and Technology (China); X. Tong, Wuhan Polytechnic Univ. (China)

In the field of image processing, an image having low contrast means that the gray values of all its pixels fall in a narrow range, if observing the histogram of this image. The low-contrast images usually look too dark or too bright due to the poor condition of illumination, such as in aerial, space and medical imaging. It is desirable to enhance these images to facilitate distinguishing the detailed information and subsequent processings. A simple method for enhancing low-contrast gray image is proposed. Based on Retinex theory, the method decomposes an image into the layers of illuminance and reflectance by using an edge-preserving low-pass filter, and separately enhances each layer. Finally, the enhanced results of these two layers are recomposed as the output. In experimens, compared with the traditional Histogram Equalization(HE)method, our enhanced results looks more satisfied in the sense that they are more like the images taken under a good condition of illumination.We believe that, our enhancement for low-contrast image as a pre-processing step, has potential in many computer vision applications, such as recognising objects under poor illuminations.

7701-38, Poster Session

Visualizing bone porosities using a tabletop scanning electron microscope

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Pores are naturally occurring entities in bone. Changes in pore size and number are often associated with diseases such as Osteoporosis and even microgravity during spaceflight. Studying bone perforations give great insight into bone's material properties, such as bone density and may contribute to identifying therapies to halt or potentially reverse bone

loss. Current technologies used in this field include nuclear magnetic resonance, micro-computed tomography and the field emission scanning electron microscope (SEM). However, limitations in each method prohibit further advancement. The objective of this experiment was to assess the effectiveness of using a new generation of analytical instruments, the TM-1000 tabletop scanning electron microscope, to analyze cortical bone porosities. Hind limb unloaded and age-based controlled mouse femurs were extracted and tested in vitro for changes in pores on the periosteal surface. An important advantage of using the tabletop is the simplified sample preparation that excludes extra coatings, dehydration and fixation steps that are otherwise required for conventional SEM. For quantitative data, pores were treated as particles in order to use an analyze particles feature in the NIH ImageJ software. Several image-processing techniques for background smoothing, thresholding and filtering were employed to produce a binary image suitable for particle analysis. It was hypothesized that the unloaded bones would show an increase in pore area, as the lack of mechanical loading would affect bone-remodeling processes taking place in and around pores. Preliminary results suggest only a slight different in frequency but not in size of pores between unloaded and control femurs.

7701-39, Poster Session

Unconstrained license plate detection using the Hausdorff distance

M. Lalonde, S. Foucher, L. Gagnon, CRIM (Canada)

This paper reports on a new technique for unconstrained license plate detection in a surveillance context. Plate detection systems that are available on the market usually rely on careful camera positioning as well as controlled illumination in order to maximize detection performance. Detecting plates using off-the-shelf surveillance cameras is more challenging due to uncertainty in plate localization and varying appearance (e.g. perspective effects).

The proposed algorithm quickly finds license plates by performing the following steps. The image is first pre-processed to extract the edges; opening with a vertical line ensures that plate sides are enhanced. Multiple scans using the Hausdorff distance are made through this vertical edge map with binary templates representing a pair of vertical lines (with varying gap to account for unknown plate size): they efficiently pinpoint areas in the image where plates may be located. Inside those areas, the Hausdorff is used again, this time over the gradient image and with a family of templates corresponding to rectangles which have been subjected to geometric transformations (to account for perspective effects). The end result is a set of plate location candidates, each associated to a confidence level that is a function of the quality of match between the image and the template.

In order to reduce false alarms, we make use of a technique developed by Loy and Barnes for symmetric shape (more specifically equiangular polygon) detection. Since Hausdorff already provides the detection hypotheses, the symmetry measurement (based on voting) supplies complementary information about each hypothesis that allows rejection of many bad candidates. Examples are given to show the usefulness of the proposed method.

7701-40, Poster Session

Thermal fluctuation exponents for two near critical point systems

B. M. Bayley, A. Oprisan, College of Charleston (United States); J. J. Hegseth, Univ. of New Orleans (United States); S. Oprisan, College of Charleston (United States); Y. Garrabos, Institut de Chimie de la Matière Condensée de Bordeaux (France); D. Beysens, Ecole Supérieure de Physique et de Chimie Industrielles (France)

Two image processing techniques are used to investigate the behavior

of the structure factor exponents related to thermal fluctuations in sulfur hexafluoride (SF6) under microgravity conditions and a density matched binary mixture of methanol and partially deuterated cyclohexane (CC*-Me) imaged on Earth. The conditions of microgravity in the pure fluid system and density matching in the binary mixture eliminate the effects of compression and sedimentation and allow the study of the statistical properties of the fluids on a microscopic scale. We used both static and dynamic structure factor methods to extract the critical exponents in the sulfur hexafluoride system. In addition to the exponents of the structure factor for both experiments, the dynamic structure factor method provided the correlation time of the fluctuations. The correlation length of fluctuations was determined by application of the autocorrelation function for sulfur hexafluoride and was examined as it evolves in time. The method of image formation was also examined and quantitatively determined for both near critical fluid systems.

7701-41, Poster Session

Real-time shot detection based on motion analysis and multiple low-level techniques

C. Cuevas, N. García, Univ. Politécnica de Madrid (Spain)

The proposed strategy combines two low-level techniques and a motion-based analysis for the detection of both abrupt and gradual transitions.

To detect abrupt transitions, first, a pixel-based analysis is carried out. Comparing the intensity level of the pixels for consecutive images, a set of possible cuts Cr is obtained. In a second step, motion analysis is applied to filter the correct ones, discarding false detections. The result of this motion analysis is the final set of abrupt transitions Kr.

For gradual transitions detection, in a first stage an edge-based analysis is performed on every image as it is received. On the results of this analysis, an evaluation begins when a shot change is defined (i.e. a final abrupt transition has been identified). Possible candidates for gradual transitions are added to the set Gs. To separate false detections form correct ones, a motion analysis (similar to that carried out for abrupt transitions) is applied. The result of this analysis is the final pruned set of gradual transitions Ks. The output of the system is the union of both abrupt and gradual final sets Kr U Ks.

Although the proposed system is able to work in real time, it has latency as the beginning of the evaluation for the possible gradual transitions requires that the last frame of the cut-limited-shot has been identified. As this latency time depends on the maximum difference between consecutive cut detections, to assure an upper bound of its value, artificial cuts in the edge-based analysis block can be inserted.

7701-42, Poster Session

A special algorithm based on structure for ship classification

J. He, Beijing Normal Univ. (China)

In the traditional pattern recognition, certain features needs to be extracted from vessels to be identified, then by comparing those features to the statistical features of different types of vessels, we can determine the vessel's type according to their similarity. In this paper, a new method for vessel recognition was proposed, in which it's unnecessary to acquire statistical features of certain vessel types. We can easily classify a satellite image's vessel according to fixed rules by calculating its aspect ratio. First, we use a morphology-based local adaptive threshold method to acquire the accurate outline of the vessel in the image, then by Radon transformation, we can find the hull's central axis through scanning in both horizontal and vertical directions of the central axis of the hull, and the aspect ratio can be correctly calculated, which provides an important basis on vessel's classification.

7701-18, Session 4

Filters and transforms to localize signal transitions

R. Sundaram, Gannon Univ. (United States)

Band-pass filters and block-based transforms are developed to retrieve signal discontinuities or transitions (edges) in sampled data. Specifically, blocks of data are transformed and filtered in the frequency domain. The zero-crossings of the filtered data are used to detect and localize the discontinuity. The discrete symmetric cosine transform (DSCT), which belongs to the class of real and circular Fourier transforms, is computed for each block of the input data. This computation is based on the even-symmetric extension of the data followed by zero-padding or data insertion. The band-pass filter coefficients are determined from truncated time-sampled or frequency-sampled forms (TSF/FSF) of the Laplacian-of-Gaussian (LOG) filter. This paper evaluates the adaptive block-based procedure to filter the data with the FSF of the LOG filter. The band-pass filter parameter is varied to classify the edges as (a) false due to noise (b) true but weak (c) true and strong. The localization error and signal-to-noise ratio (SNR) in the vicinity of the transition are expressed in terms of the filter parameter. The FSF of the LOG filter reduces the localization error and emphasizes the SNR in the vicinity of the transition. The procedure is applied to detect discontinuities in noisy data and edges in grayscale images.

7701-20, Session 4

A differential interpolation image correction approach for bidirectional resonant scanners

B. Haji-Saeed, C. L. Woods, Air Force Research Lab. (United States); J. Kierstead, Solid State Scientific Corp. (United States); J. Khoury, Air Force Research Lab. (United States)

We have developed a differential interpolation method for correcting sinusoidally scanned distorted images. In our approach, the scanned image is processed by a line-by-line interpolation technique based on differentiation. As a natural consequence of the method, the image can be divided into four domains or zones perpendicular to the scan direction. The domain boundaries are set by our interpolation algorithm. Each domain is corrected on a line pair-by-line pair basis, using simple rules that are specific to the domain. Corrected domains are reassembled to reconstruct the corrected image. The implementation of this algorithm shows that, for our 100 pixel wide test image, it is possible to retrieve at least 97.45% of the original image, as measured by the recovered energy, which is superior to other known methods we have applied to this problem.

7701-21, Session 4

Improving imaging through turbulence via aperture partitioning

B. Calef, Boeing LTS Inc. (United States)

Speckle imaging techniques make it possible to do high-resolution imaging through the turbulent atmosphere by collecting and processing a large number of short-exposure frames, each of which effectively freezes the atmosphere. In severe seeing conditions, when the characteristic scale of atmospheric fluctuations is much smaller than the diameter of the telescope, the reconstructed image is dominated by "turbulence noise" caused by redundant baselines in the pupil. I will describe a generalization of aperture masking interferometry that dramatically improves imaging performance in this regime. The approach is to partition the aperture into annuli, form the bispectra of the focal plane images formed from each annulus, recombine them into a synthesized bispectrum, and use that to retrieve the object. This may be implemented using multiple cameras and special mirrors, or with a single camera and

a suitable pupil phase mask. I will report results from simulations as well as experimental results using telescopes at the Air Force Research Lab's Maui Space Surveillance Site.

7701-22, Session 4

Superresolution of images captured from airborne unmanned vehicles

A. H. Yousef, Z. Rahman, Old Dominion Univ. (United States)

Super resolution (SR) reconstruction refers to the process of combining a sequence of under-sampled and degraded low-resolution (LR) images in order to produce a single high-resolution (HR) image. The LR input images are assumed to have slightly different views of the same scene. In broad sense, super-resolution techniques attempt to improve the spatial resolution by incorporating into the final result the additional new details that are revealed in each LR image. This can be the case of the images captured from unmanned aerial vehicles. They may have some overlap between them in addition to extra information due to the rotational parameters yaw, pitch, and roll. This extra information can be used to get a super resolution image of the common overlapped area. So, in this paper it is intended to specify a metric to determine if there is a common overlap between a set of frames and to reconstruct a super resolution image of it.

7701-23, Session 5

Networks to retrieve the regularized least-squares estimate from data

R. Sundaram, Gannon Univ. (United States)

This paper presents threshold binary networks and gradient estimation networks to retrieve information from degraded data. For instance, these networks are configured to recover the regularized least squares (LS) estimate from linearly degraded image data samples. The threshold binary networks consist of interconnections of nonlinear processing elements. The nonlinearity consists of the threshold operation applied to linear combinations of weighted binary-valued inputs to produce binary-valued outputs. The binary representation of the data is assigned to locations which are updated. For image data, this representation leads to the problem of a large number of interconnections and locations. This problem is overcome by optimizing the objective function on partitions of these representations. The partitions belong in one of two categories (1) active (2) inactive. The objective function is optimized in the active partition. The optimization proceeds until there is no reduction in the objective function from one step to the next. The optimization is continued by switching from the currently active partition to a partition chosen from the list of inactive partitions. Partitioned networks are useful in optimization problems where the error landscape consists of deep local minima. Gradient networks compute local estimates of the gradient of the objective function. The gradient is expressed as the convolution of samples of the input data with the blur sequence and the regularization sequence. Regularization controls the rate of convergence to the LS estimate. The paper discusses the application of these networks to image restoration.

7701-24, Session 5

Hierarchical layered and semantic-based image segmentation using ergodicity map

J. Yadegar, X. Liu, UtopiaCompression Corp. (United States)

Image segmentation plays a foundational role in image understanding and computer vision. Although great strides have been made and progress achieved on automatic/semi-automatic image segmentation algorithms, designing a generic, robust, and efficient image segmentation algorithm is still challenging. Human vision is still far superior compared

to computer vision, especially in interpreting semantic meanings/objects in images. We present a hierarchical/layered semantic image segmentation algorithm that can automatically and efficiently segment images into hierarchical layered/multi-scaled semantic regions/objects with contextual topological relationships. The proposed algorithm bridges the gap between semantics and low-level visual features/cues (e.g. color, intensity, edge, texture) through utilizing a layered/hierarchical ergodicity map, where ergodicity is based on a space filling fractal concept and used as a region dissimilarity measurement. The algorithm applies a highly scalable, efficient, and adaptive Peano-Cesaro triangulation technique to decompose the given image into a set of similar/homogenous regions based on low-level visual cues in a top-down manner. The layered/hierarchical ergodicity map is built through a bottom-up region dissimilarity analysis. The recursive fractal sweep associated with the Peano-Cesaro triangulation provides efficient local multi-resolution refinement to any level of details. The generated binary decomposition tree provides efficient neighbor retrieval mechanism for generating contextual topological object/region relationships. Experiments conducted within the maritime image environment, where layered semantic objects are segmented including the basic level objects (i.e. sky/land/water) and deeper level objects (in the sky/land/water-surface) are quite promising. Results demonstrate the proposed algorithm has the capability to robustly and efficiently segment images into layered semantic objects/regions with contextual topological relationships.

7701-25, Session 5

The spatial vision tree: a generic pattern recognition engine: scientific foundations, design principles, and preliminary design

Z. Rahman, Old Dominion Univ. (United States); D. J. Jobson, G. A. Woodell, NASA Langley Research Ctr. (United States)

New foundational ideas are used to define a novel approach to genericvisual pattern recognition. These ideas proceed from the starting point of the intrinsic equivalence of noise reduction and pattern recognition when noise reduction is taken to its theoretical lower limit of explicit matched filtering. This led us to the idea of full pattern specificity of a lexicon of matched filter pattern templates. A key hypothesis is that such a lexicon can be constructed and is, in fact, a generic visual alphabet of spatial vision. Hence it provides a tractable solution for the design of a generic pattern recognition engine. Here we present the key scientific ideas, the basic design principles which emerge from these ideas, and a preliminary design the Spatial Vision Tree (SVT). The latter is based upon a cryptographic approach whereby we measure a large aggregate estimate of the frequency of occurrence (FOO) for each pattern. These distributions are employed together with Hamming distance criteria to design a two-tier tree. Then using information theory, these same FOO distributions are used to define a precise method for pattern representation. Finally the experimental performance of the preliminary SVT on computer generated test images and complex natural images is assessed.

7701-26, Session 5

Study on wetland change information image segmentation based on remote sensing

J. Xu, Guangxi First Academy of Surveying and Mapping (China); X. Li, Wuhan Univ. (China)

Image segmentation is a key technique in image processing and also an essential content of image process and analysis. It decomposes an image into a number of mutual non-overlapping regions, and achieves the reasonable separation of the target and background image from the original image. Remote sensing information extraction is also a process, in which the interesting remote sensing information is separated from the remote sensing image.

At present, the majority of remote sensing information is extracted through mathematical statistics and artificial interpretation. But these approaches are characterized by low accuracy, lower efficiency, intense labor, and repeatability, so the author tries to use the method of image segmentation to segment the remote sensing images.

In this paper, the region-based image segmentation method is adopted to segment the remote sensing images after continuous analyzing and testing. The author extracts the wetland information from the remote sensing image by region-based image segmentation, and compares the segmentation results with the interpretation results by conventional methods. According to the result of the comparison, the author evaluates the image segmentation accuracy based on the common evaluation criteria that are used to evaluate the image segmentation. After analyzing the result of the segmentation evaluation, the author confirms the reliability that wetland information is extracted from the remote sensing images through the methods of region-based image segmentation.

7701-27, Session 6

Image bloom testing and analysis

M. A. Medina, J. A. Mazzetta, S. D. Scopatz, Electro Optical Industries, Inc. (United States)

The performance of imaging systems continues to increase and diversify as a result of the ability to measure, analyze, and improve the limiting aspects of optical instruments. Bloom is one such limiting aspect. In an image, bright regions of light noticeably bleed into darker regions of light causing the phenomenon referred to as "bloom", or "light bloom". The occurrence of light bloom is theoretically a direct consequence of the diffraction pattern of an aperture. In practice, bloom may also be caused both optically by non-ideal lenses and electronically by the bleeding of overly saturated pixels. In analyzing optical instruments, circular apertures are of particular interest since their theoretical diffraction patterns are well known, consisting of an Airy Disk and alternating concentric dark and bright rings. In the image formed by a circular aperture, relative intensity can be observed by dividing all pixel intensity values by the peak pixel intensity. Bloom cutoff percentages may be analyzed from their relative distances to the threshold peak intensity. Instrument performance may thus be measured against theoretical Airy function values. Additionally, polynomials of single digit orders may be accurately fit to the pixel array data. By approximating the data with polynomials pertinent information on derivatives, local slopes, and integrals may be analytically as well as numerically obtained.

7701-28, Session 6

Designing the optimal shutter sequences for the flutter shutter imaging method

J. Jelinek, Honeywell Technology (United States)

Acquiring iris or face images of moving subjects at larger distances using a flash to prevent the motion blur quickly runs into eye safety concerns as the acquisition distance is increased. For that reason the flutter shutter method recently proposed by Raskar et al. has generated considerable interest in the biometrics community. The method uses a conventional camera, whose shutter is repeatedly turned on and off during exposure to produce a uniquely blurred image, from which a sharp image of remarkable quality can be reconstructed. The paper concerns the design of shutter sequences that produce the best images. The number of possible sequences grows exponentially in both the subject's motion velocity and desired exposure value, with their majority being useless. Because the exact solution leads to an intractable mixed integer programming problem, we propose an approximate solution based on pre-screening the sequences according to the distribution of roots in their Fourier transform. A very fast algorithm utilizing the Jury's criterion allows the testing to be done without explicitly computing the roots, making the approach practical for moderately long sequences. For very long sequences, however, the candidate sequences cannot be simply generated in an exhaustive manner, but must be thoughtfully

constructed using suitably formulated necessary conditions of optimality. In the second part of the paper we show how the internal structure of the Fourier matrix constraints the candidate sequence selection.

7701-29, Session 6

Radar video digitization, network distribution, and rendering

O. Akdemir, M. Kara, T. Diler, Arastirma Merkezi Komutanligi (Turkey)

Radar video processing has been the most widely used technique to support maritime surveillance and monitoring. Todays ship borne command & control or navigation systems mostly employ analogue based radar video distribution and processing components for this purpose. Current solutions switch analogue radar signal to front-end consoles and all the processing along with radar scan conversion is performed by the embedded hardware. With the advances in the Graphical Processing Units (GPU) and the gigabit networks, new approaches have been proposed to display the radar video in the operator's screens. Some of them still entail dedicated hardware for scan conversion, whereas the others depend on the attached hardware modules to a host workstation.

Exploiting the high computing capacity of the GPUs and the higher transfer rates in the Ethernet technology, we propose architecture for the radar video processing of the maritime surveillance and monitoring. For each analogue radar in the system, a special digitizer hardware, which does not need any host computing platform, is used. Radar video is digitized right after its source, transferred with gigabit networks, post-processed and displayed at the front-end. With its embedded Ethernet module the A-Scan or B-Scan radar image is directly injected into the network by the special digitizer hardware. Consequently, received by a workstation at the console side where the image is filtered, processed and scan converted by OpenGL 2.X enabled GPU. The radar PPI image is combined with underlay and overlay graphics which may also contain map, chart or synthetic data without any additional hardware support. Our investigations on the proposed system with an average GPU that can handle about 30 frames per second rendering performance incurs 8% usage in the CPU resources. We conclude that our proposed system scales well allowing a number of radars and trackers for a typical maritime frigate platform.

7701-30, Session 6

Multiscale salient point detection in contourlet domain

R. Zewail, A. ElSafi, N. Durdle, Univ. of Alberta (Canada)

Based upon our understanding of the Human Visual System (HVS), it is believed that the human vision tends to be selectively attentive to localized "different" regions of the visual field. The detection of these localized salient regions enables the brain to perform other higher level visual tasks such as pattern recognition and object detection.

In an attempt to face some of the challenges in robust detection of salient points, we present a new method for salient point detection that is suitable for extraction of robust points of interest in complex and low quality images. The new method is based upon Non Sub-sampled Contourlet Transform (NSCT), a truly 2D multi-scale and multidirectional image analysis tool, and second moment matrix. Using the ability of the NSCT transform to capture higher order image structures, we are able to extract robust salient points in complex images that are robust to noise, rigid and non rigid deformations. .

Experiments were conducted to evaluate the robustness of the new multi-scale salient point detection method using standard test images as well as medical images. The new method has shown a superior performance compared to famous methods in the literature.

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7702-01, Session 1

Quantum informational model of 3+1 dimensional gravitational dynamics

J. Yepez, Air Force Research Lab. (United States)

Quantum information theory is undergoing rapid development and recently there has been much progress in mapping out its relationship to low dimensional gravity, primarily through Chern-Simons topological quantum field theory and conformal field theory, with the prime application of topological quantum computation. Yet, less attention has been paid to the relationship of quantum information theory to the long established and well tested theory of gravitational dynamics of 3+1 dimensional spacetime. Here I layout the case for this relationship in the weak field approximation of the 4-space metric tensor. The proposed approach considers a quantum algorithmic scheme suitable for simulating physical curved space dynamics that is traditionally described by the well known Einstein-Hibert action. The quantum algorithmic approach builds upon Einstein's veirbein representation of gravity, which Einstein originally developed back in 1928 in his search for a unified field theory and, moreover, which is presently widely accepted as the preferred theoretical approach for representing dynamical relativistic Dirac fields in curved space. Although the proposed quantum algorithmic scheme is regular-lattice based it nevertheless recovers both the Einstein equation of motion as an effective field theory and invariance of the gravitational gauge field (i.e., the spin connection) with respect to Lorentz transformations as the local symmetry group in the low energy limit.

7702-02, Session 1

Quantum algorithms for the Jones polynomial

L. H. Kauffman, Univ. of Illinois at Chicago (United States); S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States)

We discuss quantum algorithms for computing the Jones polynomial. These include our previous work, the algorithm of Aharonov, Jones and Landau (AJL) and our recent generalization of the AJL algorithm that is being used in implementing quantum calculations of the Jones polynomial via NMR.

The previous work includes our algorithm for three stranded braids that we have shown to be a part of a generalization of AJL in arXiv:0909.1080 NMR Quantum Calculations of the Jones Polynomial. Raimund Marx, Amr Fahmy, Louis Kauffman, Samuel Lomonaco, Andreas Spörl, Nikolas Pomplun, John Myers, Steffen J. Glaser.

We are in the process of writing a paper that fully generalizes AJL to new angular ranges and we are preparing new experiments in NMR related to this. This paper for the Spie conference will review the mathematical basis for this research.

7702-03, Session 1

Factorization algorithm based on the periodicity measurement of a CTES

V. Tamma, H. Zhang, X. He, Univ. of Maryland, Baltimore County (United States); A. Garuccio, Univ. degli Studi di Bari (Italy); W. P. Schleich, Univ. Ulm (Germany); Y. Shih, Univ. of Maryland, Baltimore County (United States)

The factorization of large integer numbers is a rather difficult problem in computation theory, compared with the multiplication of two integers.

In fact, the security of codes relies on this fact. Shor's algorithm would allow factorization with a polynomial number of resources, taking advantage of entanglement. In the present paper we present a new factorization algorithm, in which both number theory and physical processes allow to solve the problem of factorization. Such an algorithm, like in Shor's case, is based on the measurement of the periodicity of a known function, given by a generalized continuous truncated exponential sum (CTES), as a function of a continuous variable, which can be rescaled depending on the number to factorize. We will show that once such a periodicity is determined it is, in principle, possible to find the factors not only of one number, but of arbitrary numbers. A possible analogue computer for the implementation of such an algorithm is given by multi-path optical interferometers, with polychromatic light sources and a high resolution spectrometer. The information about the factors is encoded in the location of the interference maxima, which repeat periodically in the interferogram. We have experimentally realized such an algorithm, using a multi-path optical interferometer, with a polychromatic light source and a spectrometer, with enough accuracy to factorize any number up to seven digits, using a single measurement.

7702-04, Session 1

Lifted Jacobi equation for varying penalty parameter in the Riemannian geometry of quantum computation

H. E. Brandt, U.S. Army Research Lab. (United States)

Recent developments in the differential geometry of quantum computation are exposited. The quantum evolution is described in terms of the special unitary group of n-qubit unitary operators with unit determinant. The group manifold is taken to be Riemannian. In the present work, the lifted Jacobi equation and geodesic derivative are reviewed. This is applicable to investigations of conjugate points and the global characteristics of geodesic paths in the group manifold, and the determination of optimal quantum circuits for carrying out a quantum computation.

7702-05, Session 1

Quantum algorithms for virtual Jones polynomials via Thistlethwaite theorems

J. F. Ospina, Univ. EAFIT (Colombia)

Recently a quantum algorithm for the Jones polynomial of virtual links was proposed by Kauffman and Dye via the implementation of the virtual braid group in anionic topological quantum computation when the virtual crossings are considered as generalized swap gates.

Also recently, a mathematical method for the computation of the Jones polynomial of a given virtual link in terms of the relative Tuttle polynomial of its face (Taut) graph with some suitable variable substitutions was proposed by Diao and Hetyei. The method of Diao and Hetyei is offered as an alternative to the ribbon graph approach according to which the Tutte polynomial of a given virtual link is computed in terms of the Bollobás-Riordan polynomial of the corresponding ribbon graph. The method of Diao and Hetyei can be considered as an extension of the celebrated Thistlethwaite theorem according to which invariant polynomials for knots and links are derived from invariant polynomials for graphs.

Starting from these ideas we propose a quantum algorithm for the Jones polynomial of a given virtual link in terms of the generalized Tutte polynomials by exploiting the Thistlethwaite theorem and the Aharonov-Arab-Ebal-Landau polynomial. Our method is claimed as the quantum

versión of the Diao-Hetyei methos. Possible NMR implementations of our algortihm are discused

7702-06, Session 1

Poincare recurrence and intermittent destruction of the quantum Kelvin wave cascade in quantum turbulence

G. Vahala, The College of William & Mary (United States); J. Yepez, Air Force Research Lab. (United States); L. Vahala, Old Dominion Univ. (United States); M. Soe, Rogers State Univ. (United States)

Superfluid turbulence (i.e., a state of dense entangle quantum vortices) in a Bose-Einstein condensate (BEC) is of great interest in low temperature physics. Unlike classical vortices (or eddies), quantum vortices are well defined discrete topological singularities with zero superfluid density defining the cores. The Gross-Pitaevskii (GP) equation describes the time evolution of the BEC ground state wave function. A novel unitary quantum lattice algorithm, suitable for quantum computers, is employed with a single complex scalar boson field, whose value at a point on the lattice of spacetime points is represented by 2 complex amplitudes at that point. These local field amplitudes are subjected to a sequence of unitary collision and streaming operators which spread the entanglement throughout the lattice. The algorithm is ideal for parallel classical computers and fully respects the Hamiltonian structure of the GP equation. For the first time, we in Ref.~cite{yepez:084501} have determined the incompressible kinetic energy cascade regions for GP turbulence on grids up to 5760^3 for a single-component BEC. At large scales, where the discrete quantized nature of the vortices is unimportant, one recovers the classical $k^{-5/3}$ Kolmogorov energy spectrum. For very small scales the quantization of the vortices yields the k^{-3} quantum Kelvin wave cascade arising from Kelvin wave excitations along the vortices during vortex-reconnection.

For certain initial conditions the Poincare recurrence time can be remarkably short. Just before the Poincare recurrence there is a short time interval in which the k^{-3} quantum Kelvin wave cascade is destroyed before being reestablished. A signature of this intermittent destruction of the quantum Kelvin wave cascade can be readily seen in the time evolution of the quantum energy.

7702-07, Session 2

Jacobi fields in the Riemannian geometry of quantum computation

H. E. Brandt, U.S. Army Research Lab. (United States)

In the Riemannian geometry of quantum computation, the quantum evolution is described in terms of the special unitary group of n-qubit unitary operators with unit determinant. To elaborate on some aspects of the methodology, the generic Jacobi equation and lifted Jacobi equation, together with solutions on the group manifold, are explicitly derived. This is important for investigations of the global characteristics of geodesic paths in the group manifold, and the determination of optimal quantum circuits for carrying out a quantum computation.

7702-08, Session 2

Quantum lattice-gas model of spinor superfluids

J. Yepez, Air Force Research Lab. (United States); G. Vahala, The College of William & Mary (United States); L. Vahala, Old Dominion Univ. (United States); M. Soe, Rogers State Univ. (United States)

No abstract available.

7702-09, Session 2

Multidisciplinary intersection: strings, knots, and robotics

M. A. Johnson, The Aerospace Corp. (United States)

This paper introduces a perceived intersection of two or more disciplines from mathematical and representational perspectives. One discipline is from the realm of robotics and the others are used in the quantum information sciences. Both disciplines provide frameworks from which a robot, string, or knot can be described, modeled, or evaluated. The perceived intersection occurs when the description, model, or evaluation of the robot is analogous to that of a similarly evolved string or knot. The paper begins by presenting a topological description of a simple string. Then, the structural or kinematic description of a robotic manipulator used to mimic the string is presented. Next, identical manipulations are performed with both the string and manipulator descriptively and mathematically. As an extension, two strings shown as a braid as well as two manipulators similarly braided are presented. The presentations culminate in a simple three dimensional trefoil knot configuration using a single string and robotic manipulator. For the string manipulations topological methods found in the open literature are used. A Cartesian and/or joint reference frame is used for the robotic manipulator kinematic manipulations and representations. The two methods of representations and manipulations are compared and contrasted as well as discussion of the subsequent extension of using multi robotic interaction methods for braids and multi-knots.

7702-10, Session 2

Quantum knot theory and its applications

S. J. Lomonaco, Jr., Univ. of Maryland, Baltimore County (United States); L. H. Kauffman, Univ. of Illinois at Chicago (United States)

We present the theory of quantum knots from an intuitive perspective. A quantum knot system is a physically implementable quantum system whose states, called quantum knots, represent the spatial configuration of a closed knotted piece of rope in 3-space. The dynamic behavior of this quantum system according to Schroedinger's equation represents the movement of a closed knotted piece of rope smoothly moving through 3-space in such a way as to not pass through itself. We give two equivalent definitions, one based on mosaic knots, the other on lattice knots. The talk ends with a list of open questions.

A copy of this PowerPoint talk will be posted at: http://www.csee.umbc.edu/~lomonaco/Lectures.html

7702-11, Session 3

Optimal individual attack on BB84 quantum key distribution using single-photon two-qubit quantum logic

R. Garcia-Patron, F. N. Wong, J. H. Shapiro, Massachusetts Institute of Technology (United States)

We propose the use of single-photon two-qubit (SPTQ) quantum logic to physically simulate the optimal individual attack on Bennett-Brassard 1984 (BB84) quantum key distribution (QKD) protocol, i.e., the economical cloner. The main obstacles to implementing the economical cloner are the need for a universal two-qubit interaction and the need for a high-fidelity quantum memory. Both of these problems can be circumvented by implementing a physical simulation of the economical cloner using SPTQ logic, which exploits two independent photonic degrees of freedom to encode two qubits onto a single photon.

A universal set of gates for SPTQ-based quantum information processing was recently experimentally demonstrated by our group using deterministic linear optics. Therefore, based on that earlier work, we

believe that physically simulating the optimal individual attack on BB84 QKD is well within the experimental state of the art. A physical simulation based on SPTQ quantum logic will allow us to study the characteristics of the economical cloning attack with real apparatus, which includes the non-idealities of physical resources, while eliminating the need for the as yet unavailable high-fidelity quantum memory. The ability to implement the optimal individual attack should provide the QKD community with experimentally realistic data for testing BB84 eavesdropping vulnerability and learning about the interplay between security and post-processing protocols.

7702-12, Session 3

Comparison of quantum key distribution over fiber optics network topologies

E. J. Donkor, Univ. of Connecticut (United States)

We present a computer simulation model to characterize the performance of fiber optic networks for multiuser quantum key distribution. The networks under investigation include the RING, BUS, STAR, and wavelength router. Quantum bit-error rate is determined for each network, as function of number of users, and transmission distance. The trade off between number of uses and transmission distance is presented.

7702-13, Session 3

Experimental quantum cryptography scheme based on orthogonal states

P. Traina, M. Genovese, G. Brida, M. Gramegna, Istituto Nazionale di Ricerca Metrologica (Italy)

Since, in general, non-orthogonal states cannot be cloned, any eavesdropping attempt in a Quantum Communication scheme using non-orthogonal states as carriers of information introduces some errors in the transmission, leading to the possibility of detecting the spy. Usually, orthogonal states are not used in Quantum Cryptography schemes since they can be faithfully cloned without altering the transmitted data. Nevertheless, L. Goldberg and L. Vaidman proposed a protocol in which, even if the data exchange is realized using two orthogonal states, any attempt to eavesdrop is detectable by the legal users. In this scheme the orthogonal states are superpositions of two localized wave packets which travel along separate channels. The wave packets are not sent simultaneously towards Bob, but they are delayed by a fixed time (greater than the overall time detection accuracy) and sent one after the other. It can be shown that some tests performed by the users at the end of the communication allow the detection of the eavesdropper provided that the sending time of the bits is not publicly known. Here we present an experiment realising this scheme in which the two wavepackets correspond to two different paths inside a balanced Mach-Zehnder interferometer.

7702-14, Session 3

Efficient key integrity verification for quantum cryptography using combinatorial group testing

J. Fang, The Univ. of Hong Kong (Hong Kong, China) and South China Normal Univ. (Hong Kong, China); Z. L. Jiang, S. M. Yiu, L. C. K. Hui, The Univ. of Hong Kong (Hong Kong, China); Z. Li, Beijing Electronic Science and Technology Institute (China)

Key integrity verification is an indispensable step in quantum cryptography and it becomes an important problem in higher speed systems. Computing only one hash value for the key string is not longer an effective solution as it may lead to dropping all the bits once the hash values on both sides do not agree. In this paper, we introduce a new idea of using the technique of combinatorial group testing to design a scheme to identify the error bits to avoid dropping all the bits. Our scheme can precisely locate the error bits if the number of error bits is within the maximum set by the scheme while the overhead is insignificant based on our experiments (additional bits: 0:1% of the key; time for computing the hash values: 16ms; verification time: 22 ms). Also, even if the number of error bits is higher than the maximum set by the scheme, only some correct bits may be misclassified as error bits but not the vice versa. The results show that we can still keep the majority of the correct bits (e.g. the bits discarded due to misclassification is only 5% of the whole string even if the number of error bits is 10 times of the maximum).

7702-15, Session 3

Pauli channels exhibit a transition effect in memory estimation above a parametric threshold

M. R. Frey, Bucknell Univ. (United States); L. Coffey, Rowan Univ. (United States); L. Mentch, Bucknell Univ. (United States); A. Miller, Muskingum Univ. (United States); S. Rubin, Williams College (United States)

The communication capacities of two particular quantum Pauli channels with memory are known to exhibit a transition effect. We revisit this phenomenon from the standpoint of the functionally analogous task of channel memory estimation. We treat the complete class of Pauli channels with memory and determine the maximum quantum Fisher information achievable both with pure separable channel probe states and with maximally entangled bipartite probe states. A comparison of these Fisher informations shows that only those channels that exceed a certain parametric threshold exhibit a transition effect. For those Pauli channels that exhibit this transition effect, the memory threshold at which it occurs has a simple analytic expression.

7702-17, Session 4

Compensated crystal assemblies for type-II entangled photon generation in quantum cluster states

R. K. Erdmann, M. L. Fanto, T. McEwen, Air Force Research Lab. (United States); E. J. Galvez, Colgate Univ. (United States); A. B. U'Ren, Instituto de Ciencias Nucleares (Mexico)

Linear Optical Quantum Computation implementations require efficient sources of single and entangled photons with high mode quality. Spontaneous parametric down-conversion in nonlinear crystals can yield these but photon generation is probabilistic rather than deterministic on demand. To optimize efficiency and ultimately scalability of the process requires control of the bi-photon wavefunction's degrees of freedom particularly spectral. This has usually been achieved with spectral filtering which loses most down-converted photons. Properly selected or engineered crystal parameters can address the problem, and successful demonstrations have been carried out. However there are no natural materials to enable arbitrary application near 800 nm where photon counting has peak efficiency. A way to synthesize desired parameters using super-lattices of existing crystals has been previously analyzed but experimental demonstrations were limited to two crystals, insufficient to exploit the method's utility. We have fabricated the first prototype ten-compensated-crystal assemblies for type II down-conversion and report the results of their testing. We review implications for further prototype stages needed to address thee fabrication-tolerance control issues discovered. We discuss how the control over spectral properties offered by the methods described can enhance performance in cluster state generation and quantum optical gate configurations.

7702-18, Session 4

Radar and interferometer theories based on quantum entanglement that use N00N, M&M, or linear combinations of entangled states

J. F. Smith III, U.S. Naval Research Lab. (United States)

Different radar and interferometer designs using exotic photonic states are considered. The designs are based on quantum entanglement and use N00N states, M&M states, or linear combinations of N00N or M&M states. Performance in the presence of internal loss due to attenuation, imperfect detectors and loss due to propagation through various media is considered. The advantages and disadvantages of avoiding Fock state generation by using linear combinations of entangled states are analyzed. Proofs of the optimality of the mathematical form of the detection operators used for each class of photonic states are provided. The different types of photonic states are compared in terms of resolution and visibility, i.e. the maximum expectation of the detection operator. Closed form expressions for the bearing resolution for each type of photonic state as well as their derivations are included. The effects of the different types of loss on signal detection and resolution are considered. Inequalities are derived related to the requirements for super resolution and signal detection. In particular states that maximize resolution while keeping visibility above a certain threshold are considered. Closed form expressions for resolution, signal behavior and bounding inequalities are studied. Various propagation environments and loss models are examined. Numerical results showing system performance for different types of entangled states are discussed.

7702-19, Session 4

Superoperator analysis of entanglement in a four-qubit cluster state

G. N. Gilbert, Y. S. Weinstein, MITRE Corp. (United States)

We explore the entanglement evolution of a four-qubit cluster state in a number of decohering environments using the superoperator formalism. As a four-qubit cluster state allows the performance of an arbitrary logical qubit rotation via measurement bases quantum computation (the cluster state or one-way model), we are specifically interested in the relation between entanglement evolution and the fidelity with which the arbitrary rotation can be implemented. We concentrate on the exhibition of entanglement sudden death (ESD) and ask how severely its onset affects the utilization of the cluster state as a means of implementing an arbitrary single qubit rotation.

7702-20, Session 4

Measurement and analysis of a coupled three-particle quantum system

S. E. Rodriguez Gomez, Univ. EAFIT (Colombia)

The intrinsic quantum properties shown in electrons and atoms allow us to explode a non-classic field for the information management. Through the Stern-Gerlach device (SG), the measurement of spin via a momentum is obtained with associated probabilities due to quantum principles. This paper studies the behavior of a three-particle coupled quantum system in which a spin particle is measured by the SG apparatus while the others are not. The response of the spin-1/2 uncharged particle because of the inhomogeneous magnetic field is also analyzed introducing as well non-linear variations of the magnetic field. The system solution will be determined by specials functions according to the variation field defined

and three cases with Airy, Whittaker and Heun functions will be treated and supported by different simulations using symbolic computation with Maple.

7702-21, Session 5

Heralded single-photon partial coherence and image hiding

J. C. Howell, C. Broadbent, G. Howland, Univ. of Rochester (United States)

A large transverse diameter collimated pump beam illuminates a nonlinear crystal. Pairs are created inside of small regions of the nonlinear crystal. We can only ascertain the birth place of the photons to within a region set by the phase matching conditions. One can consider that all birthplaces are phase incoherent with other birthplaces. By measuring only the single photons, one sees a partial coherence set by the transverse width of the pump. However, by determining the birthplace by measuring the twin, the single photons partial coherence is set by the birthplace size. If a fully coherent photon strikes an image, a holographic matched filter can reveal, in a single event, the image written on the photon. However, a photon of low partial coherence cannot be deflected by the matched filter.

7702-22, Session 5

Quantum astronomy with Iqueye

C. Barbieri, Univ. degli Studi di Padova (Italy)

Iqueye is a high speed astronomical photon counting device, tested at the ESO 3.5m New Technology Telescope in La Silla (Chile). The optics splits the telescope pupil into four portions each feeding a Single Photon Avalanche Diode. A time-to-digital converter board time tags the pulses from the 4 channels, and the times sent to a storage device. The instrument is capable of running continuously up to a rate of 8MHz, with an rms accuracy better that 0.5ns. The time is obtained by means of a Rubidium clock referenced to UTC through the GPS signal. The paper describes the analysis performed on a huge amount of data, taken on bright stars in order to perform 'quantum-like' measurements in the photon stream, namely the calculation of the second-order correlation functions g2(x,0) and g2(0,t). To this end, an ad hoc software correlator has been developed. Taking advantage of the pupil-splitting concept, the calculation of g2(x,0) have been made between the sub-apertures of the telescope, as a first step to verify the zero-baseline correlation coefficient in an Hanbury-Brown Twiss intensity interferometer. In a similar way, g2(0,t) could be calculated. Although the size of the telescope did not allow an acceptable signal to noise ratio for calculating second order effects; nevertheless our experiment allowed to demonstrate the value of an Iqueye-like instrument applied to larger telescopes, like the four 8m VLTs and even more the future 42m Extremely Large Telescope for a novel exploitation of the photon stream from celestial objects.

7702-23, Session 5

Observation of two-color ghost imaging

S. Karmakar, Y. Shih, Univ. of Maryland, Baltimore County (United States)

Two-photon quantum imaging has so far demonstrated two peculiar features: (1) reproducing nonlocal image in ghost imaging type experiments and (2) improving imaging spatial resolution beyond classical limit in quantum lithography type measurements.

In this article, we wish to report an experimental study on non-degenerate two-color biphoton ghost imaging which reproduced a nonlocal ghost image and simultaneously enhanced the angular resolving power of imaging by means of greater field of view or by means of a greater imaging amplification comparing with that of classical imaging.

With the help of an entangled photon pair of $\omega_s < \omega_i$ generated from spontaneous parametric down-conversion(SPDC), we observe a ghost image with enhanced resolving power by a factor of ω_i/ω_s by means of a field of view which is $(\omega_i/\omega_s)[(d1(\omega_s/\omega_i)+d2)/(d1+d2)]$ times greater than that of the one-color ghost imaging as well as classical imaging set up, where ω_s is the frequency of signal beam that illuminates the object, ω_i is the frequency of idler beam, d1 and d2 are the optical distance from output plane of SPDC source to the imaging lens and the object plane respectively. We also wish to report the possibility of reproducing ghost image with enhanced resolving power by a factor of ω_i/ω_s by means of higher imaging amplification which is enhanced by a factor of ω_i/ω_s with the help of entangled photon pairs of $\omega_s < \omega_i$. The shorter wavelength provides better angular resolution of imaging system. But in space the shorter wavelength have more chances to be absorbed in atmosphere. That's creates the problem of enhancing angular resolution of imaging system in space. In this article, we approach the way to resolve the problem of enhancing the angular resolution in space imaging by using entangled photon pairs of $\omega_s < \omega_i$.

These reported features of two-colors ghost imaging move forward the progress of the imaging technology .

7702-24, Session 5

Low-noise amplification of a continuous variable quantum state

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The theory of an ideal, linear, phase-insensitive amplifier for an optical state is well developed. Such devices are of interest for implementing continuous variable (CV) quantum computing and quantum information protocols, in particular as part of a quantum cloner designed to make the best possible copy of a quantum state. Quantum mechanics predicts that any optical amplifier must add a certain level of noise which insures that such a device cannot be used to precisely clone an arbitrary quantum state. An amplifier that adds the lowest possible amount of noise to a quantum state is said to be quantum-noise-limited. Using such an amplifier and a beam splitter one can produce multiple copies of the input which are called "optimal quantum clones" for arbitrary Gaussian states. The cloning of a quantum state has implications in quantum information, particularly with respect to extending the range of QKD networks and also for attacking such networks.

We present an experimental realization of a low-noise, phase-insensitive optical amplifier using a four-wave mixing interaction in hot Rb vapor. Performance near the quantum limit for a range of amplifier gains, including near unity, can be achieved. We use the device to clone one half of an entangled state, and show that the final state remains entangled. This may constitute an important step along the path to cloning a complete entangled state. It also serves as an interesting system to study for the purposes of amplifying quantum information signals.

7702-25, Session 5

A weak value approach to noise

J. E. Gray, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

Noise is ubiquitous in all real systems, both classical and quantum. In most classical applications, the noise has been treated as separate from the signal, so what is measured by the detector is y = s + n, where the signal s is deterministic and the noise n is treated as a random variable. In quantum systems, s is assumed to have an underlying description that is probabilistic, so $y_{q} = s_{q}$, so the noise is often assumed to be part of the description of s_{q}. We extend the weak value formalism, using

the mathematics of characteristic functions in probability, to examine how noise can be attacked in both classical and quantum descriptions from a weak values perspective. Specifically, we treat the moments of the noise distribution as operators, so that a weak value can be used to estimate them. A detailed mathematical formalism of this and several examples will be presented in the complete paper.

7702-26, Session 5

Minimum single-photon detector bias for linear mode operation using Mach-Zehnder modulator interference

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The externally applied bias operation of linear mode avalanche photodetectors (APDs) is extended and compared to single photon avalanche photodetectors (SPADs). The minimum bias required for linear operation is calculated using the effective voltage field in the photodetector as a function of various waveforms generated through Mach-Zehnder Modulator (MZM) interference. This mode of operation reduces the amount of voltage bias needed on the detector and extends the use of SPADs into their linear regime which may enable dual-use for single photon detectors at higher photocurrents. In order to maintain photodiode linear operation- in contrast to standard nonlinear operation (or overbias) "Geiger mode" operation of SPADs- a sufficient effective field voltage must be maintained within the diode as photocurrents are increased, accounting for the dc contribution as well as the peak contribution of the incident optical field to avoid signal clipping and ensure full signal conversion. By using a Mach-Zehnder Modulator, we are able to obtain a known incident optical field, with both quantifiable dc and peak contributions utilized in various symmetric waveforms and modulation depths, as well as quantifiable non-symmetric waveforms giving various peak intensities and dc contributions. The parameters are measured from a back-illuminated 40 um high-bandwidth, high-current InGaAs photodiode with 1.330 um incident wavelength and are compared with a 1.06um InGaAsP-InP single-photon avalanche diode.

7702-27, Session 6

Indications for quantum computation requirements from comparative brain analysis

W. Baer, Naval Postgraduate School (United States); G. Bernroider, Univ. Salzburg (Austria)

The recognition of non-trivial quantum effects has become an important aspect of biological signaling studies. Examples of biological signaling studies involve the coupling of single photons in visual systems, electronic translocations in the energy transducing membranes of mitochondria, light harvesting in photosynthesis, and, more recently, enzyme-substrate interactions and weak magnetic field sensing in the avian brain (reviewed by Abott et al(eds), Quantum Aspects of Life, World Scientific, Singapore, 2008). It is a matter of debate, whether 'non-trivial'quantum calculation with functional significance can persist at 300k within typical molecular transitions times (e.g.~10-8 s, Summhammer & Bernroider, arXiv:0712.1474v1,2007). Ion transitions in the selectivity filter of voltage sensitive channels (Bernroider & Roy, SPIE 5841-29, 2005), show that coherent channel states can be found within the oxygen-cage provided by selectivity filters in channel proteins at warm temperatures. If coordination states are labeled with logical states, then the spatio-temporal organization of many filter-states provides the architecture of quantum neural computation.

The cellular organization of these membranes hosting the 'logical states' has found different evolutionary solutions in birds and mammals (e.g. Güntürkin, Current Opinion in Neurobiology, 15, 2005).

Bird and mammalian brains are quite different so common elements

indicate underlying evolutionary necessities. Both mammals and birds share organizational principles that allow for a 'segregation' of modes with different quantum state correlations suggesting the architectural precursor to quantum computation have been maintained in both evolutionary developments.

7702-28, Session 6

Design and application of a quantum compiler

T. S. Metodi, S. D. Gasster, The Aerospace Corp. (United States)

A full-scale quantum computer will be a complex interaction of both classical computer and quantum subsystems. Their realization will require significant advances in both the underlying quantum technologies that implement the qubits and gates and in the overall system level design and analysis. The implementation of a full-scale quantum application (complete with error correction) will require the orchestration of many millions of qubit interactions at each cycle of execution. In order to better understand both the system design and physical implementation we have developed a Quantum Compiler. The quantum compiler allows us to analyze the transformation and performance of a high-level quantum program that is mapped into a specific physical architecture of qubits and gates. The compiler can be applied to trade studies for optimizing reliability and latency of the program execution and to determine the error correction resources required to implement the quantum program. We describe the quantum compiler design and software implementation. The quantum compiler consist of three stages: (1) A pre-compiler that translates a human readable high-level specification of a quantum circuit into a machine readable quantum intermediate representation (QIR); (2) An assembler that maps the QIR representation of the circuit into an equivalent low-level quantum assembly representation composed of a universal set of logic gates; (3) The final stage is the assembly legalization that maps each quantum assembly-level instruction to corresponding machine instructions. The machine instructions are based on the specific technology-dependent physical architecture of the quantum computer.

7702-29, Session 6

The study of a new architecture with instruction set for quantum computer

N. Wu, F. Song, Nanjing Univ. (China); X. Li, New York City College of Technology (United States)

In this paper, we study a reliable architecture of a quantum computer and a new instruction set for the architecture, which can improve the performance and reduce the cost of the quantum computing. The criteria for experimentally implementing the scalable quantum computation on a physical device are proposed.

7702-30, Session 6

High-fidelity universal quantum gates through quantum interference

R. Li, Kent State Univ. (United States); F. Gaitan, Southern Illinois Univ. (United States)

Twisted rapid passage is a class of non-adiabatic rapid passage that gives rise to controllable quantum interference effects that were first observed experimentally in 2003 using NMR. We show that twisted rapid passage sweeps can be used to implement a universal set of quantum gates that operate with high-fidelity. This universal set G consists of

single-qubit Hadamard gate, NOT gate, the modified phase gate, the modified pi/8 gate, and the two-qubit controlled-phase gate. Sweep parameter values are provided which simulations indicate will produce the different gates in G, and for each gate, yield an error probability $Pe<10^{-4}$. Note that all gates in this universal set are driven by a single type of control field (twisted rapid passage), and the error probability of each gate falls below the rough-and-ready estimate for the accuracy threshold $Pa\sim10^{-4}$. The numerical simulations suggest that the universal gate set produced by twisted rapid passage shows promise for use in a fault-tolerant scheme for quantum computing. We discuss current challenges facing experimental implementation of this approach to universal quantum computing.

7702-34, Session 6

Gate control of a quantum dot single-electron spin through geometric phases: Feynman Dis-entangling method

S. Prabhakar, J. Raynolds, A. Inomata, Univ. at Albany (United States)

Topological manipulation of electron spins in a GaAs quantum dot is highly dedicated candidate for solid state quantum computation and non-charged based logic devices in the existing post CMOS technology. A single electron can be trapped and its spin can be manipulated by moving the quantum dot adiabatically in a closed loop (Berry effect) through the application of gate potentials. In this paper, we present numerical simulations and analytical expressions of transition probability of electron spins in single electron devices for a quantum dot. Using analytical and numerical techniques, we show that spin orbit coupling in III-V type semiconductor will enhance the transition probability of the electron spin over pure Rashba and or over pure Dresselhaus cases. With the help of Feynman Dis-entangling technique of the non-abelian operator, we found the exact analytical expression for the propagator of an electron moving under the influence of three different cases: pure Rashba, pure Dresselhaus and equal strength of Rashba and Dresselhaus spin orbit coupling. For the most general cases where the solution of the propagator becomes non-trivial, we carry out the numerical simulations of such propagator.

7702-31, Session 7

Theoretical discussion for quantum computation in biological systems

W. Baer, Naval Postgraduate School (United States)

In this paper we will present the mathematics for the model of space as a field of cells which execute a cycle of activity. We will show that the condition of stability for such activity is the minimum action principle applied to the field of space cells and that second order variations lead to oscillating terms which correspond to the deBroglie Waves of quantum theory.

Familiar biological systems have the ability to generate the illusion of space within which moving objects appear. They do so by executing a cognitive process which transforms appearances them into physical memories and measures such memories to generate the expectation of appearances in and endless event cycle. This cycle corresponds to the architecture of quantum theory because it transforms classic observables into quantum displacement waves and measures these waves to re-generate classic observables. The vonNeumann cut separates this cycle into a classic world of measurement results and a quantum world of deBroglie Waves. If instead of cutting the cycle into objective and subjective halves, we separate parallel cycles into individual space clusters we can achieve a model of physical reality that looks like a universe of interacting cognitive feedback loops. This architecture is consistent with the proposal by Archibald Wheeler that the universe is a self measuring system that can become aware of itself by executing a feedback loop around a cycle in time. We conclude that biological

systems ability to generate the illusion of space is the symptom of universal quantum phenomena.

7702-32, Session 7

YinYang bipolar quantum computing and bitwise quantum-digital cryptography

W. Zhang, Georgia Southern Univ. (United States)

This paper is based on one chapter of a working book entitled "YinYang Bipolar Relativity."

YinYang bipolar relativity is introduced that leads to a theory of bipolar quantum mechanics for bipolar quantum computing. It is shown logically that bipolar quantum entanglement and teleportation have a number of advantages including quantum-digital compatibility and the elimination for the need of conventional communication between Bob and Alice. A logical simulation of bipolar teleportation is presented.

Bipolar quantum lattice: B = {-1,0}x{0,1}.

For all bipolar variables a = (a-,a+),b = (b-,b+),c = (c-, c+),d = (d-,d+) belong to B, we have the bipolar universal modus ponens with quantum entanglement:

(a=>c; b=>d) => (a*b => c*d),

where * is a universal non-linear bipolar quantum operator that is bipolar commutative and monotonic. Bipolar quantum entanglement leads to bipolar teleportation and cryptography.

Key concept: To remain an equilibrium-based quantum logical space the bipolar quantum lattice B can no longer be further reduced. In contrast, to remain a truth-based logical space the bivalent lattice {0,1} can no longer be further reduced. Therefore, bivalent logic can be deemed the minimal but most general truth-based system; Bipolar dynamic logic (BDL) [Zhang 2009b] can be considered the minimal but most general equilibrium-based quantum logic. Without bipolarity, however, the truth values 0 and 1 are incapable of carrying any shred of direct physical syntax and semantics. A truth-based model, therefore, cannot avoid the LAFIP (logical axiomatization for illogical physics)[Zhang 2009a,b]. That could be the fundamental reason why there is so far no truth-based axiomatization for physics, no logic for particle-wave duality, bipolar disorder, big bang, black hole, and logically definable causality.

On the other hand, BDL leads to a complete background independence theory of YinYang bipolar relativity [Zhang 2009c]that achieves the difficult space and time emergence for quantum gravity. Based on the soundness and completeness of BDL, it is postulated that bipolar quantum mechanics constitutes the first complete quantum theory w.r.t. the EPR paradox. From a different perspective, bipolar relativity provides a minimal but most general equilibrium-based axiomatization of physics that constitutes a partial solution to Hilbert's Problem 6 and a unification of spacetime relativity and quantum mechanics.

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7702-33, Session 7

Hawk-Dove-Bully-Retaliator quantum game CAS aided

J. M. Lopez, Univ. EAFIT (Colombia)

The known Hawk and Dove game is analyzed from quantum mechanics with another two possible behaviors, Bully and Retaliator. The formalism used in the development of the strategies is not Dirac's due to its complex implementation in Computer Algebra System (CAS) but the matrix analysis is proposed. Both are completely alike in the results given, so the matrix method used is not less efficient than Dirac's. The classical game with the four strategies is also described and compared. As results of the quantum game, are presented pay-offs matrixes for possible players, the density matrix and its relation to quantum information and communication. Applications such as finances and biology are also presented and proposed.

Conference 7703: Independent Component Analyses, Wavelets, Neural Networks, Biosystems, and Nanoengineering VIII

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7703-02, Session 2

A geometric treatise: spectral clustering using the asymmetric adjacency matrix

H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

We will explore asymmetrical interactions among multiple neighborhoods in data sets. Such an unequal connectivity happens often in social groups. In a social group, there could be a reputation or a risk associated with a particular person (i-th person). The outward propagation of reputation vectors from the i-th person to another (j-th person) is different from any risk vectors returning to the i-th person from all j-th people. The geometric meaning of the intersection of these vectors could be interpreted as a social group. The so-called "Graph-Laplacian" matrix describing the intersection which arises from these connections turns out to be a row-less adjacency matrix: $[L]$ $[D] - [W]$. $[W]$ is the adjacency matrix of asymmetrical neighborhood connectivity whose element $W_{(i,j)}$ separated by the comma, is directional from i-th to j-th which is different from j-th to i-th. This is called a directed graph. $[D]$ is its row-sums $d_i = \sum_{(j=1)}^N W_{(i,j)}$ written in diagonal matrix form: $D_{ij} = d_i$ $_{(i,j)}$ where each i-th row represents the i-th person whose reputation is propagated to all people in the social group (N). Then, the asymmetrical Laplacian matrix $[L]$ describes the shift of the arbitrary Cartesian origin "O" to the intersection point (X_0) R^N. With the exception of those transforms that generate an equivalent planar manifold, this linear matrix system is locally generated by a Taylor expansion near the intersection point. The geometrical ramifications of such a directed graph theory will be explored herein.

7703-03, Session 2

A study of influenza A virus epitopes using genetic diffusion

P. Barbano, Yale Univ. (United States); K. A. Byrd, H. Szu, US Army RDECOM CERDEC NVESD (United States)

HxNy represents the set of all Influenza A virus subtypes belonging to the Orthomyxoviridae family, a family of viruses characterized by their highly contagious and potentially fatal outcomes. Two of the most popular Influenza A viruses are H1N1 (Swine Flu) and H3N2 (Avian Flu); in total, there are 16 HA (H1-H16) and 9 NA (N1-N9) subtypes, which are based on the antigenicity of the molecules. However, no matter the virus subtype, mutations occur, and in some cases, into potentially unknown, unlabled and thus unclassified variants. The so-called pandemic viruses are caused by genetic reassortment and interspecie transmission; thereby, introducing viruses with new subtypes into the human population. As a result, we propose to use the binary genetic code coupled with the Diffusion Geometry formulation as a means to map the mutations of HxNy viruses to the various virus subtypes and in doing so, gain insight into the evolutionary behavior and homology of such viruses.

7703-04, Session 2

Video surveillance of passengers with mug shots

M. K. Hsu, H. H. Szu, The George Washington Univ. (United States)

The authority officer relies on facial mug-shots to spot suspects among crowds. Passing through a check point, the facial displays and printouts operate in low resolution fixed poses. Thus, a databases-cuing video is recommended for real-time surveillance with Aided-Target Recognition (AiTR) prompting the inspector taking a closer second look at a specific passenger. Taking advantage of commercial available Face Detection System on Chips (SOC) at 0.04sec, we develop a fast and smart algorithm to sort facial poses among passengers. We can increase the overlapping POFs (pixels on faces) in matching mug shots at arbitrary poses with sorted facial poses. Lemma: We define the long exposure as time average of facial poses and the short exposure as single facial pose in a frame of video in 30 Hz. The fiduciary triangle is defined among two eyes and nose-top. Theorem Self-Reference Matched Filtering (Szu et al. Opt Comm. 1980; JOSA, 1982) to Facial-Pose: If we replace the desirable output of Weiner filter as the long exposure, then the filter can select a short exposure as the normal view. Corollary: Given a short exposure as normal view, the fiduciary triangle can decide all poses from left-to-right and top-to-down.

7703-06, Session 4

Multiple fractals dimensions for iris detection designed for optimal Rayleigh criteria

C. C. Hsu, Trident Systems Inc. (United States); H. Szu, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Iris is a muscle within the eyes that regulates the size of the pupil, controlling the amount of light to enter the eyes. The iris has a remarkably property that is capable of shrinking concentrically along the radial direction by a factor 4 from 2mm to 8mm. Pupil dilation and contraction make the iris texture undergoes nonlinear deformation with discrete components and minutia features. Thus, iris recognition must be scale invariant due to the pupil dynamics. We propose the Mandelbrot fractal dimension count of minutia iris details, at different intensity thresholds, in dilation-invariant wedge-boxes, formed at specific angular sizes, but spatially varying over 4 90o quadrants due to the cellular growth under the gravity. We seek a stable fractal dimensionality departed from the simple Richardson Fractal Law. Furthermore, we choose an optimum Rayleigh criterion /D matching the robust fine resolution scale for the given lens aperture D and the illumination wavelength for a potential application from a distant, with the help of comprehensive biometric including iris.

7703-07, Session 4

Multiscale directional filtering of noisy InSAR phase images

G. R. Easley, System Planning Corp. (United States); V. M. Patel, R. Chellappa, Univ. of Maryland, College Park (United States)

In this work, we present a new approach for the problem of interferometric phase noise reduction in synthetic aperture radar interferometry based on a shearlet representation. Shearlets provide a multidirectional and multiscale decomposition that has advantages when dealing with noisy phase fringes over standard filtering methods. Using a shearlet decomposition of a noisy phase image, we can adaptively estimate a denoised phase image from these coefficients in a multiscale and anisotropic fashion. Such desnoised phase interferograms can provide much better digital elevation maps (DEM). Experiments show that this method performs significantly better than other state-of-the-art methods.

7703-09, Session 6

Electronic tongue system for remote multi-ion sensing using blind source separation and wireless sensor network

W. D. Chung, F. R. G. Cruz, Chung Yuan Christian Univ. (Taiwan); H. H. Szu, The George Washington Univ. (United States); D. Pijanowska, M. Dawgul, T. Wladyslaw, Institute of Biocybernetics and Biomedical Engineering (Poland); P. Grabiec, B. Jarosewicz, Instytut Technologii Elektronowej (Poland); J. Chiang, Chung-Chou Institute of Technology (Taiwan); C. Cheng, K. Chang, W. Lin, Chung Yuan Christian Univ. (Taiwan); L. Truc, Nha Trang Univ. (Viet Nam)

This paper presents an electronic tongue system with blind source separation (BSS) and wireless sensor network (WSN) for remote multi-ion sensing applications. Electrochemical sensors, such as ion sensitive field effect transistor (ISFET) and extended gate field effect transistor (EGFET), only provide combined concentration of ions in aqueous solutions. Mixed hydrogen and sodium ions in chemical solutions are observed by means of H+ ISFET and H+ EGFET sensor arrays. The BSS extracts concentration of individual ions using independent component analysis (ICA) implemented in field programmable gate array platform (Spartan-3A DSP 1800 FPGA). Selectivity coefficients (K) of sensors serve as a priori knowledge that helps solve BSS problem. Both fixed interference method (FIM) and fixed principal method (FPM) are conducted for better K determination. Using wireless transceivers (nRF24L01), ISFET/EGFET modules are realized as wireless sensor nodes. The integration of WSN technology into the electronic tongue system with BSS capability makes distant multi-ion measurement viable for environment and water quality monitoring.

7703-10, Session 6

Feature extraction and selection strategies for automated target recognition

W. N. Greene, Princeton Univ. (United States); H. Braun, Arizona State Univ. (United States); W. Edens, Butler Univ. (United States); T. T. Lu, T. Chao, Jet Propulsion Lab. (United States)

Feature extraction and selection concerns transforming and reducing potential target data into smaller and more useful forms as well as selecting important subsets of features for target detection and classification. Several feature extraction and selection methods are studied for automatic target recognition (ATR) system using JPL's Grayscale Optical Correlator (GOC) and Optimal Trade-Off Maximum Average Correlation Height (OT-MACH) filter. The ATR system is composed of three stages: a cursory region-of-interest (ROI) search using the GOC and OT-MACH filters, a feature extraction and selection stage, and a final classification and verification stage that employs a neural network and a support vector machine (SVM). The feature extraction and selection strategies were built around two popular extraction methods: Principal Component Analysis (PCA) and Independent Component Analysis (ICA). Variations of feature extraction methods have been examined such as PCA with whitening (PCAW), mutual information feature selection (MIFS), etc. Performance was measured and compared based on the classification accuracy, false alarm rate and receiver operating characteristic (ROC) output of a neural net classifier and SVM. Fast training and accurate target recognition have been achieved using sonar and video images of real world scenarios.

7703-11, Session 6

Border security and surveillance with smart cameras and motes in a SensorWeb

S. Guler, intuVision, Inc. (United States); T. Cole, Northrop Grumman Mission Systems (United States)

This paper describes research and development for surveillance system that leverages smart sensor, intelligent video and SensorWeb technologies to aid in border patrol operations to enhance the security of borders and critical infrastructures. Intelligent video has emerged as a promising tool amid growing concern about border security and vulnerable entry points. Numerous barriers exist that limits the effectiveness of surveillance video in large area protection; such as large volumes of data to be processed, lack of smart sensors to detect potential threats and limited bandwidth to capture and distribute video data.

We present a solution addresses these obstacles by employing a Smart Video Node in a Sensor Web framework. Smart Video Nodes, consisting a camera and video event detection capability are cued by inexpensive sensor motes to detect existence of motion or pressure that may indicate human or vehicle activity. Based on sensor motes' observations cameras are slewed to observe the activity and intelligent video analysis detects potential threats to be disseminated as "alerts". SensorWeb framework enables quick and efficient identification of available sensors, collects data from disparate sensors, automatically tasks various sensors based on observations or events received from other sensors, and receives and disseminates alerts from multiple sensors. The prototype system is implemented by leveraging intuVision's intelligent video, Northrop Grumman's SensorWeb technologies.

Implementation of a deployable system with Smart Video Nodes and sensor motes within the SensorWeb platform is currently underway. The final product will have many applications in commercial, government and military systems.

7703-12, Session 6

Smart sensing system

C. C. Hsu, Trident Systems Inc. (United States); K. Chu, U.S. Dept. of Homeland Security (United States); J. O'Looney, M. I. Blake, Trident Systems Inc. (United States)

A highly-distributed, fault-tolerant, and energy-efficient Semantic Smart Sensing System is presented to efficiently provide a 24/7 and all weather security operation in crowded environments or restricted areas. The system consists of distributed sensor nodes integrated with specific passive sensors to rapidly collect, process, and disseminate heterogeneous sensor data from near omni-directions. The sensor nodes can cooperatively work to send immediate security information when new objects appear. Once the new objects are detected, the system will smartly select available nodes with a PTZ EO/IR camera to track the objects and capture associated imagery. The system provides applicable advanced on-board digital image processing capabilities to detect and track the specific objects. In the system, all the sensor nodes are connected with a robust, reconfigurable, LPI/LPD (Low Probability of Intercept/ Low Probability of Detect) wireless mesh network using Ultra-wide band (UWB) RF technology. The Service Oriented Architecture enables remote applications to interact with the system network and use the specific presentation methods. In addition, the system is compliant with Open Geospatial Consortium - Sensor Web Enablement (OGC-SWE) standards to efficiently discover, access, use, and control of heterogeneous sensors and their metadata. These system capabilities and technologies have great potential for both military and civilian applications, enabling highly effective security support tools for improving surveillance activities in densely crowded environments. It would be directly applicable to solutions for emergency response personnel, law enforcement, and other homeland security missions, as well as in applications requiring the interoperation of sensor networks with handheld or body-worn interface devices.

**Conference 7703: Independent Component Analyses,
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SPIE
Defense,
Security + Sensing

7703-13, Session 7

Proactive learning for artificial cognitive systems

S. Lee, Korea Advanced Institute of Science and Technology (Korea, Republic of)

The Artificial Cognitive Systems (ACS) will be investigated for human-like functions such as vision, auditory, inference, and behavior. Especially, computational models and artificial HW/SW systems will be devised for Proactive Knowledge Development (PKD) and Self-Identity (SI). The PKD model provides bilateral interactions between robot and unknown environment (people, other robots, cyberspace). For the situation awareness in unknown environment it is required to receive audio-visual signals and to accumulate knowledge. If the knowledge is not enough, the PKD should improve by itself though internet and others. For human-oriented decision making it is also required for the robot to have self-identify and emotion. Finally, the developed models and system will be mounted on a robot for the human-robot co-existing society.

Based on the computational models of PKD and SI, we would like to build functional modules for Knowledge Represenation (Basic units of knowledge, i.e., features, and hierarchical network architecture based on the features), Knowledge Accumulation (Self-learning knowledge accumulation from environment), Situation Awareness (Recognition of unknown environment and situation based on knowledge, previous experience, and self-identity), Decision Making (Decision making based on situation, models of the users, and its own internal states), and Human Behavior (Action model for facial expression, hand motion, and speeches).

The developed ACS will be tested against the new Turing Test for the situation awareness. The Test problems will consist of several video clips, and the performance of the ACSs will be compared against those of human with several levels of cognitive ability.

7703-14, Session 7

Learning one-to-many mapping functions for audio-visual integrated perception

S. Lee, J. Lim, D. Oh, Korea Advanced Institute of Science and Technology (Korea, Republic of)

Two approaches for the integration of audio and visual perception will be presented. One approach tries to map the visual data into audio data with possible one-to-many mapping. The other uses top-down attention to make classification decision based on the differences between expected and actual sensory data for both audio and visual data.

7703-15, Session 7

Multiple optimal learning factors for feed-forward networks

S. Malalur, M. T. Manry, The Univ. of Texas at Arlington (United States)

A batch training algorithm for feed-forward networks is proposed which consists of two steps per epoch. In the first step, Newton's method is used to estimate a separate optimal learning factor for each hidden unit's input weights. In the second step, orthogonal least squares (OLS) is used to solve linear equations for the network's output weights. The use of OLS prevents potential damage to the input weight Jacobian matrix due to linearly dependent hidden units.

The Gauss-Newton Hessian matrix H2 for this multiple optimal learning factors (MOLF) method is clearly much smaller than the Hessian matrix H1 for the entire network. Elements of H2 are shown to be weighted sums of elements from H1. In addition, it is shown that H2 remains nonsingular, even when some network inputs are linearly dependent.

MOLF is shown to be about as efficient per epoch as backpropagation (BP) and conjugate gradient (CG), with similar numbers of required multiplies. In several examples using publicly available data sets, MOLF is shown to perform better in terms of 10-fold training and validation errors. Also, MOLF performs as well as or better than Levenberg-Marquardt, with several orders of magnitude fewer multiplies.

7703-16, Session 7

CORDIC algorithms for SVM FPGA implementation

H. R. Lamela, J. Gimeno Sarciada, M. Jiménez, Univ. Carlos III de Madrid (Spain)

Support Vector Machines are currently one of the best classification algorithms used in a wide number of applications. The ability to extract a classification function from a limited number of learning examples keeping in the structural risk low has demonstrated to be a clear alternative to other neural networks.

However, the calculations involved in computing the kernel and the repetition of the process for all support vectors in the classification problem are certainly intensive, requiring time or power consumption in order to function correctly. This problem could be a drawback in certain applications with limited resources or time. Therefore simple algorithms circumventing this problem are needed.

In this paper we analyze an FPGA implementation of a SVM which uses a CORDIC algorithm for simplifying the calculation of as specific kernel greatly reducing the time and hardware requirements needed for the classification, allowing for powerful in-field portable applications. The algorithm is and its calculation capabilities are shown. The full SVM classifier using this algorithm is implemented in an FPGA and its in-field use assessed for high speed low power classification.

7703-18, Session 9

CONTACT: sensors for aerospace and Fano-resonance photonic crystal cavities

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Seven Texas universities and the Air Force Research Laboratory are working on a program of research aimed at sensors, energetic materials, power generation and storage, and nanomaterials for potential aerospace applications. The program seeks to provide new technology and also a trained workforce for taking nanoscience to market. In this regard, the CONTACT Program has connection with more than twenty industrial firms and seeks to use resources including the Rice Alliance to foster new spin-off and startup companies, linking new ideas with venture capital and business development. One of the projects in the sensors area is focused on narrow wavelength sensitive sensors. Here, we report theoretical and experimental investigations of infrared absorption characteristics for PbSe/PbS colloidal quantum dots (CQDs) in defect-free photonic crystal cavities, via Fano resonances. Experimental demonstration at the center absorption wavelength near 1550 nm was made on patterned single crystalline silicon nanomembranes (SiNMs) on transferred flexible PET substrates and on Si-on-insulator (SOI) substrates with PbSe/PbS CQDs backfilled into the air holes of the patterned SiNMs. Optical properties were directly measured. The Fano resonance showed red-shift due to increased refractive index in the air hole region of the patterned SiNMs. More importantly, significant absorption enhancement was found at Fano resonance due to the strong interaction between CQDs and matched Fano resonances. Otherwise, no absorption enhancement was observed. We will also report different CQD filling factors and the effectiveness of these techniques on the spectral and absorption properties of CQDs in both narrow band Fano filters and broadband reflectors.

Conference 7703: Independent Component Analyses,
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7703-19, Session 9

Nano-photonics: past and present

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Nanotech is at the scale of 10-9 meters, located at the mesocopic transition phase, which does not require a QM description (the microscopic world of a single atom at 10-10 meters). However, QM principles aid the understanding of any unusual property at the nanotech level. The major difference between nano-photonics and other forms of optics is that the nano-scale is not very 'hands on'. For the most part, we will not be able to see the components with the naked eye, but will be required to use some nanotech imaging tools.

7703-20, Session 9

The role of extensive variables in nanoscience

J. E. Gray, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

Thermodynamics has been cast in terms of a few variables that completely characterize a physical system; such variables are subdivided into two types: extensive and intensive. Extensive variables are those which grow linearity with the size of a system such as entropy, volume, and heat capacity. Temperature and specific heat do not depend on the size of a system, so they are termed intensive variables. Thermodynamics starts to break down at the nano scale and we need a concept the captures what is causing the breakdown or allows us to extend the concept of extensive to the nano scale. To illustrate this non-extensive feature we introduce the concept of degree of non-extensivity and illustrate it at the nano-scale. We then use it to suggest that the concept of generalized extensivity, introduced by Addison and Gray, can be used to fix many of the problems associated with the break down of extensiviity. We then discuss how variables that obey a principle of generalized superposition, hence generalized extensivity, emerge at the nano-scale. We then discuss some of the consequences of generalized extensivity at the nano scale.

7703-21, Session 10

Watermarking strategies for IP protection of microprocessor cores

L. Parrilla, E. Castillo, A. García, Univ. de Granada (Spain); U. Meyer-Bäse, Florida State Univ. (United States); E. Todorovich, E. Boemo, Univ. Autónoma de Madrid (Spain); D. González, A. Lloris, Univ. de Granada (Spain)

Reuse-based design has emerged as one of the most important methodologies for integrated circuit design, with reusable Intellectual Property (IP) cores enabling the optimization of company resources due to reduced development time and costs. This is of special interest in the Field-Programmable Logic (FPL) domain, which mainly relies on automatic synthesis tools. However, this design methodology has brought to light the intellectual property protection (IPP) of those modules, with most forms of protection in the EDA industry being difficult to translate to this domain. However, IP core watermarking has emerged as a tool for IP core protection. Although watermarks may be inserted at different levels of the design flow, watermarking Hardware Description Language (HDL) descriptions has been proved to be a robust and secure option.

A new framework for the protection of μP cores is presented. The protection scheme is derived from the IPP@HDL procedure and it has been adapted to the singularities of μP cores, overcoming the problems for the digital signature extraction in such systems. Additionally, the feature of hardware activation has been introduced, allowing the distribution of μP cores in a "demo" mode and a later activation that can

be easily performed by the customer by executing a simple program. Application examples show that the additional hardware introduced for protection and/or activation has no effect over the performance, and showing an assumable area increase.

7703-22, Session 10

C2H hardware acceleration of the Epsilon quadratic sieve algorithm

U. Meyer-Bäse, G. Botella, Florida State Univ. (United States); E. Castillo, A. García, Univ. de Granada (Spain)

Tools and algorithms how to efficiently divide Hardware and Software of an application (a.k.a. HW/SW codesign) has been intensively studied in the past decade. Altera has developed a unique design flow based on the NIOS embedded processor and a C-source to Hardware (C2H) compiler that allow HW/SW codesign exploration on a high level by changing a few parameter in the C source code only. The underlying data path, control unit, Avalance bus and memory are generated by C2H for the FPGA HW. This kind of Hardware acceleration is a vital tool for software engineers who need to increase the performance of their embedded software applications. Hardware accelerators can take full advantage of the parallel processing structure of the FPGA to calculate more computations per clock cycle than general-purpose CPUs and can deliver orders-of-magnitude increase in performance.

The polynomial quadratic sieve (QS) algorithm is one of the most powerful algorithms to factor large composite primes used to break RSA cryptographic systems. The HW structure of the QS algorithm seems to be a good fit for FPGA acceleration. Our new epsilon QS algorithm further simplifies the hardware architecture making it an even better candidate for C2H acceleration. This paper shows our design results in FPGA resource and performance when implementing very long arithmetic on the NIOS microprocessor platform with C2H acceleration for different libraries (LIP, FLINT, GMP) and QS architecture choices for factoring 32-2048 bit RSA numbers.

7703-23, Session 10

Multimodal image-based emotional state assessment

J. A. Skipper, T. R. Schneider, D. T. Petkie, Wright State Univ. (United States)

The objective of this work is to identify and fuse salient features extracted from an integrated a multisensor imager suite that includes commercial-off-the-shelf electro-optical (EO) and infrared (IR) sensors, along with a state-of-the art, high definition, three-dimensional (HD3D) spatial phase imager (SPI). The data will be fed into newly developed algorithms designed to effectively characterize a human subject's affective (emotional) state.

7703-24, Session 10

Optimization of a hardware implementation for pulse coupled neural networks for image applications

H. R. Lamela, J. Gimeno Sarciada, M. Ruiz-Llata, Univ. Carlos III de Madrid (Spain); C. Warde, Massachusetts Institute of Technology (United States)

Pulse Coupled Neural Networks are a very useful tool for image processing and visual applications, since it has the advantages of being invariant to image changes as rotation, scale, or certain distortion. Among other characteristics, the PCNN changes a given image input into a temporal representation which can be easily later analyzed for pattern recognition.

Practically all of the wavelet denoising methods rely on the second-order statistics of signal and noise. Although there are some similarities, using higher-order statistics for denoising is fundamentally different from second-order methods. In higher-order statistical denoising, a second-order cross-correlation function is calculated rather than a wavelet coefficient. Then, the third-order correlation coefficient is calculated from the cross-correlation function. A binary mask is computed by applying a hard threshold to the third order coefficients. The mask is one if the coefficient is above the threshold, otherwise it is zero.

Using optimal thresholds we statistically determined thresholds in terms of a multiple of the standard deviation of third-order correlation coefficients.

7703-32, Session 13

Comparative analysis of filtered back-projection algorithms for opto-acoustic imaging

R. Gutiérrez, H. R. Lamela, D. C. Gallego, A. Martín, Univ. Carlos III de Madrid (Spain); A. A. Oraevsky, Fairway Medical Technologies, Inc. (United States)

Various types of cancer remain the second leading cause of death in many countries of the world. Optoacustic imaging, a novel imaging technique, offers high contrast and resolution to detect solid tumors by meassuring the pressure waves generated by tissues exposed to optical energy. Several algorithms, based on Back Projection techniques, have been suggested to process OA images in conjunction with signal filtering.

An exact time-domain reconstruction formula based on measured pressure for the three common measurement geometries has been reported (M. Xu and L. V. Wang, 2005). It produces images with excellent resolution (sharp boundaries) but poor contrast. As a solution for this problem, some approximate time-domain filtered back-projection (FBP) reconstruction algorithms have also been reported. In order to sharpen object boundaries while simultaneously preserving high contrast of the reconstructed objects, a wavelet transform implementation using a wavelet family resembling the theoretical N-shaped OA signal can be used (A. A. Oraevsky, 2008). Images are obtained first using a multiresolution wavelet-based signal processing over OA signals and subsequently using a radial BP algorithm.

Our results consist of two parts: (1) reconstructions from simulated OA data to test the image contrast resulting from various reconstruction algorithms implementations, and (2) analysis of experimentally obtained images based on data collected from a physical phantom. Our analysis demonstrated that the image of back-projected wavelet-transformed and simultaneously integrated OA pressure signals possesses the highest contrast and resolution sufficient for the clear definition of the object boundaries.

7703-34, Session 14

The hidden impact of inter-individual genomic variations on cellular function

H. Bolouri, C. Georgescu, California Institute of Technology (United States)

Systems biology has dramatically changed our understanding of cellular function. Common disorders are increasingly seen as the outcome of widespread interactions among large numbers of genes and pathways. At the same time, studies of genetic and epigenetic variability within and across populations have revealed enormous inter-individual variability. Medical diagnosis and treatment will ultimately need to be individualized.

 Within a few years, we will be able to sequence the entire genome of any individual for O($1000). Using systems biology to combine personal genomes with biomarker data, we will be to identify specific - and multiple - dysregulated pathways and systems in the patient. Drugs and devices can then be designed to target very specific sub-processes associated with the needs of each patient. I will review how a confluence of biological, technological and methodological developments is making it possible to provide highly personalized diagnoses and treatments.

7703-35, Session 15

Systems biology and computational methods for lipidomics analysis: understanding lipidomic networks in glioblastoma cancer cells

A. D. Meyer-Bäse, Florida State Univ. (United States)

The goal of the present paper is to analyze and interpret lipidomic data sets acquired by high-throughput measurements such as nano liquid chromatography (nano-LC) separation followed by detection with high mass accuracy and high mass-resolving power 14.5 FT-ICR MS. The samples were taken from the U87 cell line treated under seven different treatments. We hypothesize that the observed correlations between the gangliosides concentrations are a result of the underlying lipidomic reaction network. Thus, lipidomic networks in glioblastoma represent highly dynamical processes continuously changing under the influence of fluctuations. These induce a specific pattern of correlations and are measured in the experiment as a result of network propagation.

As seen in plant metabolism, the determined pair-wise correlations represent a snapshot or "finger print" of the biochemical state of the glioblastoma cell at a given point in time. We introduce a novel concept in correlation network, the so-called graph clustering approach, which results in finding not only the correlations but also the clusters in these networks providing thus based on the concept of modularity a better visualization and analysis in lipidomic data exploration.

The theoretical results have important implications in reverse engineering, although previous work showed that the covariance matrix does not always have enough information to fully specify a system and additional knowledge must be made acquired.

In summary, this paper revealed in an unique way the "fingerprints" in lipidomics showing us how gene therapy (adeno virus) with wild type p53 followed by chemotherapy with the topoisomerase inhibitor SN38 induces 95% apoptosis (cell death).

7703-36, Session 15

Variable patch sizes for normalized cross correlation in image pairs

J. Wang, M. A. Pratt, H. Chu, Univ. of Louisiana at Lafayette (United States)

Matching two image patches is an important step in many multi-image analyses. Most matching algorithms rely on maximizing the correlation between two patches. This problem is prevalent among many signal processing applications, such as pulsed radar signal processing, stereo vision for depth recovery and biometric recognition. Correlation-based matches are often used in such registration applications. The performance of correlation-based matching algorithms such as the Normalized Cross Correlation (NCC) depends on the image patch size used in the computation. In this paper, we present a new method to determine the patch size for each candidate point used in the NCC computation. Instead of using patches with a fixed size, we locate those patches that are distinguishable from all other patches at a patch size. When a patch is indistinguishable, we increase the patch size until they are distinguishable. When the patch size grows to be impractically large, those patches can be abandoned. The new method seeks the best balance point between matching performance and computational cost in NCC computation. Experimental results demonstrate the performance of our method.

7703-37, Session 15

A comparative analysis of Laplacian and diffusion maps used for IR human detection

K. A. Byrd, M. Chouikha, Howard Univ. (United States)

The development of robust human detection systems continues to be a major thrust of Department of Defense organizations. Limitations such as variations in pose, partial occlusion and change in physical appearance continue to impede the progress of vision experts studying this problem. These systems are also limited by issues in the sensor domain, namely uncontrollable lighting and weather conditions during the acquisition of data. In lieu of these limitations, the research community continues to grow, and in doing so, has moved away from the traditional pixel-based approaches in support of new approaches based on spectral graph theory. These so-called spectral clustering methods have proven to be very effective in finding low-dimensional descriptions of data embedded in high dimensional spaces. In this paper, we present a comparative analysis of the Laplacian and Diffusion Map clustering techniques used for IR human detection.

7703-38, Session 15

Imaging in the 21st Century: a new paradigm

W. T. Rhodes, Florida Atlantic Univ. (United States)

No abstract available

7703-39, Session 16

Recognizing foreground - background interaction

J. C. Jenkins, J. P. Reynolds, H. Szu, U.S. Army RDECOM CERDEC NVESD (United States)

Can the background affect the foreground target in distant, low-quality imagery? If it does, it might occur in our mind. How could we be sure about this in the psychophysical sense? We will begin with the physiology of our brain's homeostasis, of which an isothermal equilibrium is characterized by the minimum of Helmholtz Free Energy: H = E - T0S $\geq$ 0, where T0 = 37°C, the Boltzmann Entropy S = KBln(W), and E is the unknown internal energy to be computed. We assume that a pre-attentive recognition is effortless, meaning H = 0 implying E = T0S, Q.E.D. [1] We estimate the brain memory space to be proportional to the image size. We further approximate a distant, low-quality image in terms of sparse binary macro-pixels of connected ones among zeros. Then, the image phase space is W , where the total number of macro-pixels N=P0+P1+P2+ for the i-th class of macro-pixels (i=0,1,2, respectively for zero, single ones, paired ones). Besides occlusion, a natural physical interaction is shadowing, which may form paired macro-pixels; ones from the foreground, while the others the background. By computing the entropy reduction due to shadowing which creates edge elements, we have proven the existence of a physical interaction for pre-attentive "pop-out" [2]. We will simulate and verify the effortless theorem through an Internet based delivery system.

Ref: 1. Szu, H.: US PTO 7,355,182 (Apr. 8, 2008); loc.cit. 7,366,564 (Apr. 29, 2008)

2. Bela Julesz, "Early vision & focal attention," Rev. Mod. Phys. 63, pp.735-772, 1991.

7703-40, Session 16

Neurobiological inspired visual velocity estimation system based on a new hierarchical information bottleneck filter

M. M. Ahmad Al-Bajari, Technische Univ. Berlin (Germany)

Recently, vision based 3D motion estimation has became one of the most active research topics in mobile robot guidance systems. These are often based on geometrical model assumptions or on optical flow (OF). However, the real world challenges present a set of difficulties for which the conventional machine vision methods are not adequate.

Here, a novel, biological inspired method to estimate the 3D translational and rotational velocity of a robot is presented, which addresses these real world challenges. Inspired by neurophysiology findings, we have developed a new artificial neural network (ANN) based filter, which models velocity selective neurons, whose activities correlate with velocity of optical structures. It reduces image dimensionality while perceiving velocity information using the maximum mutual information (MMI) criterion.The developed IB/MMI filter is applied in a hierarchical scheme.

The trained system has been tested in a variety of indoor environments. It shows good generalization performance. Our model

links advanced ANN technology to biological findings and approximating the true velocity.

7703-42, Session 16

Study on the technique of distinguishing rock from coal based on statistical analysis of fast Fourier transform

T. Gu, L. Xu, North China Institute of Science and Technology (China)

An algorithm of distinguishing rock from coal based on statistical analysis of Fast Fourier Transform (FFT) is presented which can be used in the mechanized caving coal locales. First, eight groups of sound signals sampled with the speed 8192 samples/sec during caving are transformed by FFT. Second, the FFT results are analyzed and the ratios of the low frequency energy to the high frequency energy(ER) defined in the FFT results are calculated by using the variance analytical method (Var). Third, the typical values of the sound of the coal bumping the transporting coal armor plate, the rock bumping the armor plate and the mixing of coal and rock bumping the armor plate are calculated with the variances and the ratios(EV= ER *Var). Finally, the threshold of distinguishing rock from coal is evaluated by using the typical values and used to direct the opportunity for caving. We can learn by the experimental results that the proposed technique can depict effectively the different characteristics of the sampled signals. The experimental results also show that we can distinguish effectively different bumping sounds of coal, rock and the mixing of them by the characteristics when adjusting the threshold value. Therefore the algorithm can be used to improve the miners' productivity and promote the construction of digital mine.

**Conference 7703: Independent Component Analyses,
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7703-43, Session 16

Evaluation model for the implementation results of mine law based on neural network

T. Gu, L. Xu, North China Institute of Science and Technology
(China)

To evaluate the implementation results of mine safety production law,
the evaluation model based on Neural Network is presented. In this
model, 63 indicators which can describe the mine law effectively are
proposed. The evaluation system is developed by using the model and
the 63 indicators. The evaluation results show that the proposed method
has high accuracy. We can effectively estimate the score of one mine for
its carrying out the safety law. The estimate results are of the scientific
credibility and impartiality.

Conference 7704: Evolutionary and Bio-Inspired Computation: Theory and Applications IV

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Evolutionary and Bio-Inspired Computation: Theory and Applications IV

7704-01, Session 1

Cross domain intelligence sharing for mobile devices

J. Spina, Air Force Research Lab. (United States)

Abstract - Although more information than ever before is available to support the intelligence analyst, the vast proliferation of types of data, devices, and protocols makes it increasingly difficult to ensure that the right information is received by the right people at the right time. It becomes even more challenging when the information has security classifications that need to be processed as well. This paper investigates methods and procedures for handling and disseminating intelligence information to groups of users that possess varying security classifications. The cross-domain implications are critical in that users must only be allowed access to information that meets their clearance level. The ability to securely manage and deliver critical knowledge and actionable intelligence to the analyst regardless of device configuration (bandwidth, processing speed, etc.), classification level or location in a reliable manner, would provide the analyst 24/7 access to useable information. There are several important components to an intuitive system that can provide timely information in a user-preferred manner. Besides the ability to format information to accommodate the user's profiles, it's very important to address multi-level security, which could provide ability to properly send classified information across different domains, thus enabling faster dissemination of time critical information. These topics will be the main theme of this paper.

7704-02, Session 1

Experimenting with social network analysis techniques in a net-centric environment

P. M. LaMonica, T. V. Waskiewicz, Air Force Research Lab. (United States)

The Air Force Research Laboratory's Information Directorate has begun researching methods for deploying social network analysis techniques in a net-centric environment. This research is part of a larger program known as Net-Centric Exploitation and Tracking (NCET) whose objective is to precisely identify, geo-locate, and track persons of interest based on a net-centric environment of cooperative tactically deployed nodes with organic sensing, processing, information management and communications. The research includes employing the most appropriate metrics and explores how to utilize social network techniques in a net-centric environment. Net-centric environments pose many challenges because they are continuously evolving and possess numerous interconnected nodes. The social network analysis metrics leverage communication data to derive key players, detect groups, and discover links and preliminary results from experiments are provided.

7704-03, Session 1

Neural methods based on modified reputation rules for detection and identification of intrusion attacks in wireless ad hoc sensor networks

W. S. Hortos, Associates in Communications Engineering Research and Technology (United States)

A wireless ad hoc sensor network is a configuration for area surveillance that affords rapid, flexible deployment in arbitrary threat environments,

e.g., battlefield spaces or enterprise premises. With no infrastructure support, sensor nodes communicate with each other only when they are within wireless transmission range. The nodes are typically unattended and severely resource-restricted, with limited processing, memory, and power capacities. They operate cooperatively to process and fuse sensor data into information to fulfill the surveillance mission. In a wireless sensor network (WSN), each sensor at a node observes physical phenomena in its sensing range. Node processing quantizes and combines, or fuses, the observations to produce aggregate information; processing occurs along an intermediate sequence of wirelessly linked nodes that ultimately reaches the sink (destination) node. The wireless medium can be easily eavesdropped; links forming network paths and their constituent nodes can be compromised by intrusion attacks from malicious agents operating outside the network or internally at the nodes. Node compromise can introduce uncertainty in aggregate information. A compromised node may completely reveal its operations to the adversary, thereby rendering purely cryptographic approaches vulnerable. Finding methods to secure the process of data fusion against attacks by compromised nodes and to quantify the uncertainty that may exist in the fused results becomes a critical issue in mitigating the effects of intrusion attacks.

In previous work by the author, parameters from network protocol layers were selected as features in supervised and unsupervised algorithms that detect and identify certain intrusion attacks on WSNs conveying multi-sensor data. The algorithms improved the residual performance of intrusion prevention measures provided by dynamic key-management schemes and trust models implemented among nodes. The unsupervised algorithms are not trained on the signature of known attack traffic; instead, the unsupervised anomaly detection techniques learn the signature of normal network traffic. However, the accuracy of the detection and identification results for the unsupervised approach is significantly lower than those for the supervised learning techniques applied to the same scenarios of intrusion attacks.

Furthermore, traditional intrusion detection systems, based on pattern matching and static cryptographic signatures, are limited in their response to the continuous evolution of the attacks against WSNs, since the traditional systems need up-to-date and comprehensive knowledge bases. Data mining techniques have been successfully applied in host-based intrusion detection approaches, but application of these techniques on raw network data is complicated by the enormous size of the input data that could potentially exhaust the limited processing resources of WSNs. The limitations of these alternate approaches motivate a new unsupervised approach to intrusion detection and identification in which the set of discrimination features, consisting of the parameters from the WSN protocol layers, is augmented with the security attributes and quantified trustworthiness (reputation) levels, established during the data exchanges among nodes to achieve fusion results.

Published research by others has introduced the concept of the trustworthiness (reputation) of a single sensor node. Reputation is evaluated using an information-theoretic concept, the Kullback-Leibler (KL) distance. The KL distance can be added to the set of security features. In the process of data fusion, an opinion - a metric of the degree of belief - is generated to represent the uncertainty in the aggregated result. As the aggregate (fused) information is disseminated along network routes to the sink node(s), its corresponding opinion is propagated and regulated by Josang's belief model. Following this model, the uncertainty within the sensor data and their aggregation can be effectively quantified throughout the network for use in security algorithms. In principle, the concept of opinion, as a metric of subjective belief, can be used to interpret the degree of trust about the fused result. By applying subjective logic on the opinion to manage trust propagation, the uncertainty inherent in fused results can be precisely quantified for use in decision making by the security algorithms.

Closer examination of the published research however reveals key assumptions on the concepts of reputation and opinion to evaluate the uncertainty of a fused result that preclude their application to security algorithms for dynamic WSNs in arbitrary threat environments. The

published notion of reputation assumes that the system of data sources is stationary. Moreover, the authors of the published research introduce a computational algebra to generate the sequence of propagated opinion (reputation) values of fused results along network routes that leads to increasingly complex calculations of opinion at limited processors at successive nodes, that is, to excessive overhead in the data fusion process. In the present work, the concept of reputation, and, hence, opinion, are modified to allow their application to WSNs. One modification is the incorporation of the sequence of sensed-data acquisition times together with the temporal correlation of data from like-kind sensors to evaluate the opinion of fused results. The second modification reduces the computational complexity of opinion evaluation for propagated fusion results; the computation is decomposed into a sequence of processing steps, alongside the information aggregation processing at successive nodes. Each step computes the interim value of opinion at a processing node along a route, based on opinion values associated with fused results from preceding nodes along tributary routes. Each of these opinion values is conveyed by a mobile software agent issued from a preceding node. In this way, the modification distributes the reputation (opinion) computation of the last fused result over the processing resources of the nodes along the route to the sink. In summary, the inclusion of reputation as a factor in the determination of interim aggregate information is equivalent to implementation of a reputation-based security filter at each processing stage of data fusion.

The integration of our modified concept of reputation into the sensor-data fusion process improves the intrusion detection and identification results based on the unsupervised anomaly detection technique of the probabilistic neural network (PNN). The reputation-based version of the PNN learns the signature of normal network traffic with the random weights typically used in the PNN replaced by the trust-based quantified reputation of sensor data or subsequent aggregate (fused) information generated by our sequential implementation of a temporal version of Josang's belief model.

A two-stage algorithm, that detects network intrusions and then identifies the detections, is implemented to overcome the problems of large sensor data loads and resource restrictions in WSNs. The first stage is a clustering algorithm that reduces the data payload to a tractable size. In the first stage, a neural-network (NN) algorithm based on the modified reputation model is implemented via a system of mobile software agents; the agents adapt to available resource capacities at the nodes to effect the parallel distributed computation of successive reputation values that are used in the generation of aggregate (fused) information. The revised algorithms reduce complexity, distribute storage utilization, and respond robustly to variability in sensor data. Dimensionality reduction due to the NN clustering algorithms produces further reductions in communication costs and energy consumption. The second stage is an anomaly detection algorithm is a version of a support vector machine (SVM) based on the modified reputation model; the algorithm efficiency is improved by the availability of knowledge on the sensor data payload. Unsupervised learning methods are applied to the SVM for classification of the intrusion attacks.

The detection and identification performance of the two-stage algorithm is assessed in simulations of WSN scenarios with multiple sensors at edge nodes for known intrusion types: black hole, flooding, Sybil, and other denial-of-service attacks. The simulation results demonstrate improved robustness of the two-stage design based on reputation-based NNs to intrusion anomalies from compromised nodes and external intrusion attacks. The proposed classifiers based on the temporal and distributed modification of the original belief models and the associated reputation-based neural networks disperse the short- and long-term memory of the sensor inputs. The proposed classifiers thereby function as security alerts when anomalous inputs are detected. The performance results also reveal a complementary advantage: the framework based the temporal and distributed modification of the belief models represents a powerful mechanism for quantification of uncertainty in WSNs. The approach can thus purge false data to accomplish robust aggregation in the presence of multiple compromised nodes.

7704-04, Session 1

Entropyology: the application of bioinformatics and data modeling to digital virus and malware recognition

H. M. Jaenisch, J. W. Handley, Licht Strahl Engineering, Inc. (United States)

Malware are analogs of viruses. Viruses are comprised of large numbers of polypeptide proteins. The shape and function of the protein strands determines the functionality of the segment, similar to a subroutine in malware. The full combination of subroutines is the malware organism, in analogous fashion as a collection of polypeptides forms protein structures that are information bearing. We propose to apply the methods of Bioinformatics to analyze malware to provide a rich feature set for creating a unique and novel detection and classification scheme that is originally applied to Bioinformatics amino acid sequencing. Our proposed methods enable real time in situ (in contrast to in vivo) malware detection applications.

7704-05, Session 1

Intelligent visualization techniques in computational lipidomics

A. D. Meyer-Bäse, Florida State Univ. (United States)

Intelligent and multitiered quantitative analysis of biological systems is rapidly evolving to a key technique in studying the biomolecular cancer aspects. Newly emerging advances in both measurement as well as bio-inspired computation techniques have facilitated the development of so-called lipidomics technologies and offer an excellent opportunity to understand regulation at the molecular level in many diseases such as cancer.

In this paper, we propose novel techniques based on intelligent clustering such as graph-clustering and on neural-processing-derived stochastic equations to model the interactions at the molecular level and to study the success of novel gene therapies for eradicating the aggressive glioblastoma. These new paradigms are providing unique "fingerprints" by revealing how the intricate interactions at the lipidome level can be employed to induce apoptosis (cell death) and are thus opening a new window to biomedical frontiers.

7704-06, Session 2

Applying Efficient Global Optimization (EGO) to large dimensional optimizations: a wide-band fragmented patch example

T. H. O'Donnell, H. L. Southall, B. Kaanta, S. G. Santarelli, H. Steyskal, Air Force Research Lab. (United States)

Efficient Global Optimization (EGO minimizes expensive cost function evaluations by correlating evaluated parameter sets and respective solutions to model the optimization space. For optimizations requiring destructive testing or lengthy simulations, this computational overhead represents a desirable tradeoff. However, the inspection of the predictor space to determine the next evaluation point can be a time-intensive operation. While conducted for limited parameters by exhaustive sampling, this method is not extendable to large dimensions. We apply EGO here to the 11-dimensional optimization of a wide-band fragmented antenna patch, and present "branch and bound" and other potential approaches for selecting the next evaluation point.

7704-07, Session 2

Optimum design of antennas using metamaterials with the Efficient Global Optimization (EGO) algorithm

H. L. Southall, T. H. O'Donnell, J. S. Derov, Air Force Research Lab. (United States)

Efficient Global Optimization (EGO) is a competent evolutionary algorithm which minimizes expensive cost function evaluations by correlating previous solutions to intelligently select the next point to evaluate. Having previously demonstrated EGO on a limited-parameter array optimization, in this paper we present a more-complex optimization of a wideband folded bowtie antenna element over a metamaterial groundplane. Using Matlab and Ansoft HFSS (High Frequency Structure Simulator), we apply EGO to optimize: the diameter and depth of the metamaterial; the height of the antenna element above the groundplane and the element length, to achieve the best antenna performance in the most compact size.

7704-08, Session 2

Multiple tests for wind turbine fault detection and score fusion using two-level multidimensional scaling (MDS)

X. Ye, W. Gao, Y. Yan, L. A. Osadciw, Syracuse Univ. (United States)

Wind is an important renewable energy source. The energy and economic return from building wind farms justify the expensive investments in doing so. However, without an effective monitoring system, under-performing or faulty turbines will cause a huge loss in revenue. Early detection of such failures help prevent these undesired working conditions. We develop three tests on power curve, rotor speed curve, pitch angle curve of individual turbine. In each test, multiple states are defined to distinguish different working conditions, including complete shut-downs, under-performing states, abnormally frequent default states, as well as normal working states. These three tests are combined to reach a final conclusion, which is more effective than any single test.

Through extensive data mining of historical data and verification from farm operators, some state combinations are discovered to be strong indicators of spindle failures, lightning strikes, anemometer faults, etc, for fault detection. In each individual test, and in the score fusion of these tests, we apply multidimensional scaling (MDS) to reduce the high dimensional feature space into a 3-dimensional visualization, from which it is easier to discover turbine working information. This approach gains a qualitative understanding of turbine performance status to detect faults, and also provides explanations on what has happened for detailed diagnostics.

The state-of-the-art SCADA (Supervisory Control And Data Acquisition) system in industry can only answer the question whether there are abnormal working states, and our evaluation of multiple states in multiple tests is also promising for diagnostics. In the future, these tests can be readily incorporated in a Bayesian network for intelligent analysis and decision support.

7704-09, Session 2

Leftover parts in the biomimetic agenda

H. V. D. Parunak, NewVectors LLC (United States)

Biological systems have proven a rich source of inspiration for engineered systems with highly desirable properties, such as distribution, decentralization, and dynamic adaptation. However, the inspiration has been selective. Certain features, such as interaction through a shared environment, are very widely imitated. Others are less frequently exploited. These include the process of speciation, courtship signals,

and death. Based on twenty-five years of experience in engineering biomimetic systems for real-world applications, this invited talk will consider the potential contributions of some of these less-used mechanisms to solving real-world problems.

7704-10, Session 3

Two satellite image sets for the training and validation of image processing systems for defense applications

B. J. Herzog, Univ. of Alaska Anchorage (United States); M. R. Peterson, Univ. of Hawai'i (United States); F. W. Moore, Univ. of Alaska Anchorage (United States)

Many image processing algorithms utilize the discrete wavelet transform (DWT) to provide efficient compression and near-perfect reconstruction of image data. Defense applications often require the transmission of data at high levels of compression over noisy channels. In recent years, evolutionary algorithms (EAs) have been utilized to optimize image transform filters that outperform standard wavelets for bandwidth-constrained compression of satellite images. The optimization of these filters requires the use of training images appropriately chosen for the image processing system's intended applications. This paper presents two robust sets of fifty images each intended for the training and validation of satellite and unmanned aerial vehicle (UAV) reconnaissance image processing algorithms. Each set consists of a diverse range of subjects consisting of cities, airports, military bases, and landmarks representative of the types of images that may be captured during reconnaissance missions. Optimized algorithms may be "overtrained" for a specific problem instance and thus exhibit poor performance over a general set of data. To reduce the risk of overtraining an image filter, we evaluate the suitability of each image as a training image. After evolving filters using each image, we assess the average compression performance of each filter across the entire set of images. We thus identify a small subset of images from each set that provide strong performance as training images for the image transform optimization problem. These images will also provide a suitable platform for the development of other algorithms for defense applications. The images are available upon request from the contact author.

7704-11, Session 3

Evolved image compression transforms

F. W. Moore, B. J. Babb, Univ. of Alaska Anchorage (United States); M. R. Peterson, Univ. of Hawai'i (United States)

State-of-the-art image compression and reconstruction schemes utilize wavelets. Quantization and thresholding are commonly used to achieve additional compression, but cause permanent, irreversible information loss. This paper describes an investigation into whether evolutionary computation may be used to optimize forward (compression-only) transforms capable of matching or exceeding the compression capabilities of a selected wavelet, while reducing the aggregate error in images subsequently reconstructed by that wavelet. Transforms are independently trained and tested using three sets of images: digital photographs, fingerprints, and satellite images.

7704-12, Session 3

Application and evaluation of novel optical-flow-based motion correction algorithms to breast MRI

G. Botella, A. D. Meyer-Bäse, Florida State Univ. (United States)

Motion induced artifacts represent a major problem in detection and diagnosis of breast cancer in dynamic contrast-enhanced magnetic

resonance imaging. In this paper, we present and evaluate two novel optical-flow-based motion correction algorithms. Subsequently, we evaluate qualitatively and quantitatively the performance of these motion compensation techniques.

Based on several simulation results, we determined the optimal motion compensation parameters, the optimal feature number and tested different classification techniques.

Our results have shown that motion compensation can be of crucial value both in medical as well as industrial applications.

7704-13, Session 3

Evolving matched filter transform pairs for satellite image processing

M. R. Peterson, Univ. of Hawai'i (United States); F. W. Moore, B. J. Babb, Univ. of Alaska Anchorage (United States)

Wavelets provide an attractive method for efficient image compression. For transmission across noisy or bandwidth-limited channels, a signal may be subjected to quantization in which the signal is transcribed onto a reduced alphabet in order to save bandwidth. Unfortunately, the performance of the discrete wavelet transform (DWT) degrades at increasing levels of quantization. In recent years, evolutionary algorithms (EAs) have been employed to optimize wavelet-inspired transform filters to improve compression performance in the presence of quantization. Wavelet filters consist of a pair of real-valued coefficient sets; one set represents the compression filter while the other set defines the image reconstruction filter. The reconstruction filter is defined as the biorthogonal inverse of the compression filter. Previous research focused upon two approaches to filter optimization. In one approach, the original wavelet filter is used for image compression while the reconstruction filter is evolved by an EA. In the second approach, both the compression and reconstruction filters are evolved. In both cases, the filters are not biorthogonally related to one another. We propose a novel approach to filter evolution. The EA optimizes a compression filter. Rather than using a wavelet filter or evolving a second filter for reconstruction, the reconstruction filter is computed as the biorthogonal inverse of the evolved compression filter. The resulting filter pair retains some of the mathematical properties of wavelets. This paper compares this new approach to existing filter optimization approaches to determine its suitability for the optimization of image filters appropriate for defense applications of image processing.

7704-14, Session 4

Cognitive dynamic logic algorithms for situational awareness

L. I. Perlovsky, Air Force Research Lab. (United States)

No abstract available.

7704-15, Session 5

Multimedia information extraction technology: barriers and pathways

J. S. Garofolo, National Institute of Standards and Technology (United States); S. M. Walter, Air Force Research Lab. (United States)

Significant performance improvements have been achieved over the last twenty years in computer analysis of text, audio, still imagery and motion imagery, but performance peaks are being observed, the pace of breakthrough algorithmic improvements is slowing, and pipelining these technologies for analysis of multimedia has achieved very limited success. The goal of the emerging technology of multimedia information extraction (MMIE) is to improve the quality and quantity of information extraction from multimedia sources and, potentially, provide some new ideas for research in component media research areas. The gargantuan amounts of multimedia now appearing on the Internet and elsewhere is necessitating an acceleration of work in the analysis of multimedia and, unfortunately, there are multidisciplinary and technical barriers to research and development in this area. This paper identifies challenges that must be overcome to enable critical development and speed progress in multimedia information extraction technologies, reviews some of the arising requirements for the technology, and discusses current and upcoming research and projects.

7704-16, Session 5

Combining motion understanding and keyframe image analysis for broadcast video information extraction

M. Chen, A. G. Hauptmann, H. Li, Carnegie Mellon Univ. (United States)

Our current work is focused on action recognition in broadcast video. To this end we developed a new algorithm to detect and describe spatio-temporal interest points. In part-based methods, there are three major steps: detecting interest points, constructing a feature descriptor, and building a classifier. Detecting interest points reduces the whole video from a volume of pixels to compact but descriptive interest points. Therefore, we desire to develop a detection method, which detects a sufficient number of interest points containing the necessary information to recognize a human action. The MoSIFT algorithm detects spatially distinctive interest points with substantial motion. We first apply the well-known SIFT algorithm to find visually distinctive components in the spatial domain and detect spatio-temporal interest points with (temporal) motion constraints. The motion constraint consists of a 'sufficient' amount of optical flow around the distinctive points.

We applied this motion-based analysis of video together with traditional keyframe image analysis based on color moments and the SIFT descriptor applied to the keyframe to extract semantic concepts that require understandingof the visual scene as well as the motion. Examples of the 20 evaluated concepts include "playing soccer", "people dancing", "plane flying". The performance for video high-level concept detection was evaluated by NIST using the 2009 TRECVID dataset consisting of 100 hours of foreign broadcast video for training/development and 180 hours of foreign broadcast video for testing. Our approach resulted in excellent results for motion related semantic concepts and significantly better than average performance for static object concepts.

7704-17, Session 5

Human emotion detector based on genetic algorithm using lip features

T. S. Brown, G. Fetanat, A. Homaifar, North Carolina A&T State Univ. (United States); B. H. Tsou, O. L. Mendoza-Schrock, Air Force Research Lab. (United States)

We predicted human emotion using Genetic Algorithm (GA) on lip features extracted from the facial images. Our emotion detection attempted to classify all seven universal emotions of fear, happiness, dislike, surprise, anger, sadness and neutrality. First, the input images are processed using methods, such as region of interest (ROI) acquisition, grayscale, histogram equalization, filtering, and edge detection for extracting the lip object. Next, the GA determines the optimal or near optimal ellipse parameters that circumvent and separate the mouth into upper and lower lips. The two ellipses then went through fitness calculation and are followed by training using a database of Japanese women faces expressing all seven emotions. Finally, our proposed algorithm was tested using a published database consisting emotions from several persons. The final results are then presented in confusion matrices. Our results showed an accuracy that varies between 20%

to 60% for each of the seven emotion. The errors are mainly due to inaccuracies in the classification, and different expressions of the given emotion in the database. Detailed analysis of these errors points out to the limitation of emotion detection that is based on the lip features alone. Similar work has been done in literature for emotion detection of only one person's emotion expressions. Here, we have successfully extended our GA base solution to include several subjects.

7704-18, Session 5

Long-range audio and audio-visual event detection using a laser Doppler vibrometer

T. Wang, Z. Zhu, The City College of New York (United States); A. Divakaran, Sarnoff Corp. (United States)

Association of audio events with video events presents a challenge to a typical camera-microphone method in order to capture AV signals from a large distance, since it requires a long range microphone array, and geo-calibration of both audio and video sensors, which is difficult to carry out with high accuracy. In this work, in addition to a geo-calibrated electro-optical camera, we propose to use a novel optical sensor - a Laser Doppler Vibrometer(LDV) for real-time audio sensing, which allows us to use the same geo-calibration for both the camera and the audio (via LDV). We have promising preliminary results with associating the audio recording of speech with the video of the human speaker.

7704-19, Session 6

Mosaic-based 3D scene representation and rendering of circular aerial video

E. Molina, Z. Zhu, The City College of New York (United States); O. L. Mendoza-Schrock, Air Force Research Lab. (United States)

Circular aerial video provides a persistent view over a scene and generates a large amount of imagery, much of which is redundant. The interesting features of the scene are the 3D structural data, moving objects, and scenery changes. Mosaic-based scene representations have worked well in detecting and modeling these features while greatly reducing the amount of storage required to store a scene. In the past, mosaic-based methods have worked well for video sequences with camera paths with a dominant motion direction. Here we expand on this method to handle circular camera motion. By using a polar transformation about the center of the scene, we are able to transform circular motion into an approximate linear motion. This allows us to employ proven stereo mosaic, 3D reconstruction and moving object detection methods that we have developed. Once features are found, they only need to be transformed back to the cartesian space from the polar space for feature interpretation and exploitation, such as, 3D measurements and classification.

7704-20, Session 6

Discriminative features and classification methods for accurate classification

M. P. Dessauer, S. Dua, Louisiana Tech Univ. (United States)

Automated classification and tracking approaches suffer from the high-dimensionality of the data and information space and frequently rely upon discriminative feature selection, and efficient and accurate supervised classification strategies. Feature selection strategies have the benefit of representing the data in a modified reduced space to improve the efficacy of data mining, machine learning and computer vision approaches. We have developed feature selection methods involving feature ranking and assimilation to discover reduced feature-sets that produce accurate results in classification for automated classifiers with significant specificity and sensitivity. We have tested a wide range of spatial, texture, and wavelet-based feature sets for electro-optical (EO), infrared (IR), and

synthetic aperture radar (SAR) on several machine-learning algorithms for classification for performance evaluation and comparison. Detailed experimental evaluation is provided for classification accuracy of the features and classifiers on the particular data sets, accompanied by a discussion for the particular success or failure. In the second section, we detail our novel feature set that fuses and weights descriptors, which produces high, robust classification accuracy when input into a classifier. Our method leverages information previously calculated in the detection stage, which includes Hessian determinants, wavelet decomposition, and texture statistics. This decision reduces computation time because no new feature value calculations are necessary. We demonstrate the results of our feature set implementation and discuss ways for creating classifier decision rules to adaptively choose a particular classification algorithm, which is dependent on certain operating conditions or data types.

7704-21, Session 6

Wavelet-based image registration

C. Paulson, Univ. of Florida (United States); S. Ezekiel, Indiana Univ. of Pennsylvania (United States); D. O. Wu, Univ. of Florida (United States)

Image Registration is a fundamental enabling technology in computer vision. Developing an accurate image registration algorithm will significantly improve other computer vision problems such as tracking, fusion, change detection, etc. In this paper, the goal is to create an algorithm that reduces the Root Mean Square Error (RMSE) around 4 and increases the Peak to Signal Noise Ratio (PSNR) above 34 by using the wavelet coefficients to extract feature points, do feature point correspondence, and register images. Since this research deals with wavelet coefficients, two algorithms were developed; one algorithm uses the approximate coefficients, while the other uses the detailed coefficients. The preliminary results show that the algorithm is able to achieve a PSNR of approximately 33 and RMSE of approximately 5. This paper provides a comprehensive explanation of the wavelet based registration algorithms for Remote Sensing applications.

7704-22, Session 6

Multi-scale graph theoretic image segmentation using wavelet decomposition

M. P. Dessauer, S. Dua, Louisiana Tech Univ. (United States)

We present a novel implementation of multi-scale graph-theoretic image segmentation using wavelet decomposition. This bottom-up segmentation through weighted agglomeration approach utilizes the specific statistical characteristics of vehicles to quickly detect regions of interest in image frames. The method incorporates pixel intensity, gradients, texture, and histogram values to detect salient segments at multiple scales. Wavelet decomposition creates gradient and image approximations at multiple scales for fast edge weighting between nodes in the graph. Nodes with strong edge weights merge to form a single node at a higher level, where new internal statistics are calculated and edges are created with nodes at the new scale. Top-down saliency energy values are then calculated for each pixel at every scale, with the pixel labeled as a member of the node (segment) at the scale of highest energy. Salient node information is then used for binary classification as potential object or non-object for passing to classification and tracking algorithms. The method provides multi-scale segmentations by agglomerating nodes that consisted of finer node agglomerations (lower scales). Criteria for weights between nodes included multi-level features such as average intensity, variance, and boundary completion values. This method has been successfully tested on electro-optical (EO), infrared (IR), and synthetic aperture radar (SAR) data sets with multiple varying operating conditions (OCs). It has shown to successfully segment both full and partially occluded objects with minimal false alarms and false negatives. This method can easily be extended to produce more accurate segmentations through sensor fusion of registered data types.

7704-23, Session 6

Manifold learning and the CAESAR database

O. Mendoza-Schrock, J. Patrick, G. Arnold, M. Ferrara, Air Force Research Lab. (United States)

Understanding and organizing data is the first step toward exploiting sensor phenomenology for dismount tracking. The Civilian American and European Surface Anthropometry Resource (CAESAR) database, provided by Air Force Research Laboratory (AFRL) Human Effectiveness Directorate and SAE International, is a rich dataset containing 40 traditional, anthropometric measurements and full body scans of over 4000 human subjects. The contribution of this paper is to explore the existing database to determine what measurable characteristics, or combinations of measureable characteristics, can be used to classify the dataset by demographics including gender, age, and race. Once characteristics are identified that allow for demographic classification, sensed data can be better exploited, and tailored to capture the measurements necessary for classification. This research will apply toolsets typically used for sensor exploitation of rigid objects to the 40 measurements from the CAESAR database in an effort to contribute to this long-standing problem.

7704-24, Session 6

Activity and function recognition for moving and static objects in urban environments from wide-area persistent surveillance inputs

G. M. Levchuk, Aptima Inc. (United States); A. F. Bobick, Georgia Institute of Technology (United States); E. Jones, Aptima Inc. (United States)

Existing methods for object classification rely primarily on static information available in single-frame images. The data from long-range video surveillance assets are usually not sufficient to distinguish the objects from one another, and even if high-resolution data were available, the visual features alone would not allow determination of the intent or purpose of the objects that are of high interest to military intelligence analysis. Persistent video surveillance is a source of motion and temporal activity data that promises to enable automated object intent classification.

In this paper, we describe a model for recognizing activities and functions of moving and static objects using the motion information from low-resolution video inputs. The model is based on representing the activities and functions using three variables: (i) time; (ii) space; and (iii) structures. Time variables deal with the fact that activities occur over time, and the particular time and/or duration of the behavior or its component events might indicate its class. Space variables allow reasoning about interactions between objects and incorporate the geographic context into the reasoning. Finally, structures among actors and activities, which include semantic, syntactic, and lexical constraints and relationships, are essential to distinguish activities composed of multiple lower-level events and involving multiple actors. Our algorithms achieved a high accuracy of activity and function recognition in the experiments using surveillance data collected by Angel Fire platform.

7704-25, Session 6

Contrast equalization methods for layered-sensing systems

R. Van Hook, J. R. Layne, Air Force Research Lab. (United States)

In this paper we evaluate several methods to perform histogram equalization under the layered sensing construction. Layered sensing is a new construct in the repertoire of the US Air Force. Under the layered sensing paradigm, an area is surveyed by a multitude of sensors at varying altitudes, and operating across many modalities. This combination of sensors provides better insight into a situation than could ever be achieved with a single sensor. A fundamental requirement to utilize this technology is to first perform histogram equalization of the data from each of the individual sensors. The contribution of this paper is to explore and provide an evaluation of various techniques for histogram equalization of Electro-Optical (EO) video sequences taken from under the layered sensing construct whose views are centered on a city.

7704-26, Session 6

Sensor agnostics for networked MAV applications

A. K. Mitra, Air Force Research Lab. (United States); T. B. Goodwin, Northrop Grumman Electronic Systems (United States); R. R. Selmic, Louisiana Tech Univ. (United States)

We discuss a number of potential advantages associated with a new concept denoted as Sensor Agnostic Networks. For this particular paper, we focus primarily on integrated wireless networks that contain one or more MAVs (Micro Unmanned Aerial Vehicle). We present several approaches to analysis and design of Sensor Agnostic Networks based on assuming canonically structured architectures that are comprised of low-cost wireless sensor node technologies. We provide a logical development that motivates the potential adaptation of distributed low-cost sensor networks that leverage state-of-the-art wireless technologies and are specifically designed with pre-determined hooks, or facets, in-place that allow for quick and efficient sensor swaps between cost-low RF Sensors, EO Sensors, and Chem/Bio Sensors. For example, for purposes of performing RF Functions using new low-cost sensor agnostic approaches, we outline two RF system synthesis procedures denoted as "Position-Adaptive Multi-UAV Radar Functions Using Asynchronous Step-Frequency Waveforms" and "Position-Adaptive MAV Sensors for RF Direction Finding". We show that these advanced approaches to distributed RF sensing are accessible by the adaptation of structured and low-cost wireless modules such as Wi-Fi, Zigbee, Bluetooth, and State-of-the-Art Wireless Motes. This treatment includes a number of original approaches to distributed system design such as the introduction of, for example, building-to-building dynamic/ smart multi-MAV perching strategies in response to excitations from RF signal scattering/propagation trends that are integrated within position-adaptive objective control functions. We also discuss sensor exploitation for baseline cases that involve MAV-integrated and networked EO technologies and also cite other potential advanced applications such as RF thru-wall sensing. In addition, we conceptualize and investigate potentially limiting cases for our Sensor Agnostic Approach to design by discussing the potential incorporation/integration of more novel sensor technologies such as MAV-integrated sensor skins with integrated luminescent/fluorescent sensing capabilities. The final section includes a discussion of recent results obtained via the prototyping and testing of our customized MAV-integrated chem/bio technologies for sensing in remote and inaccessible environments via a low-cost sensor agnostic approach. All of the sample design synthesis procedures provided within this paper conform to the structural low-cost electronic wireless network architectural constraints adopted for our new approach to generalized sensing applications via the conscious integration of Sensor Agnostic capabilities.

7704-27, Session 6

Applying multimodal discourse analysis to the study of image-enabled communication

J. Snyder, Syracuse Univ. (United States)

No abstract available

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7705-01, Session 1

CULA: hybrid GPU accelerated linear algebra routines

J. R. Humphrey, Jr., K. E. Spagnoli, A. L. Paolini, D. K. Price, E. J. Kelmelis, EM Photonics, Inc. (United States)

The modern graphics processing unit (GPU) found in many standard personal computers is a highly parallel math processor capable of nearly 1 TFLOPS peak throughput at a cost similar to a high-end CPU and excellent FLOPS/watt. High level linear algebra operations are computationally intense, often requiring O(N3) operations and would seem a natural fit for the processing power of the GPU. Our work is on CULA, which is an GPU accelerated implementation of linear algebra routines. We present results from factorizations such as LU decomposition, singular value decomposition and QR decomposition along with applications like system solution and least squares.

The GPU execution model featured by Nvidia GPUs based on CUDA demands very strong parallelism, requiring between hundreds and thousands of simultaneous operations to achieve high performance. Some constructs from linear algebra map extremely well to the GPU and others map poorly. CPUs, on the other hand, do well at smaller order parallelism and perform acceptably during low-parallelism code segments. Our work addresses this via hybrid a processing model, in which the CPU and GPU work simultaneously to produce results. In many cases, this is accomplished by allowing each platform to do the work it performs most naturally.

7705-02, Session 1

Accelerating the finite difference time domain (FDTD) method with CUDA

J. F. Stack, Jr., Remcom, Inc. (United States)

Advances in a variety of fields ranging from cellular phone design to MRI coil design necessitate the use of high accuracy electromagnetic computational methods such as FDTD to analyze complex new products. Such high fidelity techniques generally yield highly accurate results at the cost of increased computation time. The advent of NVIDIA's CUDA technology allows this time to be reduced by orders of magnitude but introduces new programming challenges not previously encountered by software developers.

This discussion enumerates the most pressing GPU challenges and techniques to overcome these issues. A simplistic C implementation of the FDTD method will be employed to explore the effects of divergent branches on CUDA kernels, and memory bottlenecks are overcome through the usage of memory coalescing, constant memory, and shared memory. After considering the necessary optimizations, timing comparisons between optimized CPU and GPU implementations of a commercial FDTD code are given.

7705-04, Session 1

Novel high-fidelity realistic explosion damage simulation for urban environments

X. Liu, J. Yadegar, Y. Zhu, C. Raju, J. Bhagavathula, UtopiaCompression Corp. (United States)

Realistic building damage simulation has significant impact in modern modeling and simulation systems and has great potential in diverse panoply of military and civil applications such as training and mission planning. Realistic building damage simulation should incorporate accurate physics based static/dynamic explosion models, rubble generation, rubble flyout, and interactions between flying rubble and their surrounding entities. However, none of the existing building damage simulation systems sufficiently faithfully realize the criteria of realism required for effective military applications. In this paper, we present a novel high-fidelity and efficient/runtime physics-based explosion damage simulation system to realistically simulate primary/secondary destruction to buildings. In the proposed system, we utilize a highly efficient and scalable tetrahedral decomposition approach to realistically simulate rubble formation based on the collision force and material property. A family of novel blast models (including spherical, non-spherical, spherical/non-spherical with reflectance, etc,) are applied to accurately and realistically simulate explosions based on static/dynamic detonation conditions. The proposed system also takes account of rubble pile formation and more poignantly applies a generic and scalable multi-component-based object representation to describe scene entities and highly scalable agent-subsumption architecture and scheduler to schedule clusters of sequential and parallel events. Experimental results show that the proposed system has the capability to realistically simulate rubble generation, rubble flyout and their primary and secondary impacts on surrounding objects including buildings, structures, vehicles and pedestrians in clusters of sequential and parallel damage events, where rubble flyout is simulated as a "burst" of fragments with variable speed, mass, and geometric shape realistically.

7705-05, Session 2

Depth estimation, spatially variant image registration, and super-resolution using a multi-lenslet camera

M. S. Mirotznik, Univ. of Delaware (United States); Q. Zhang, Wake Forest Univ. (United States)

With a multi-lenslet camera, we can capture multiple low resolution (LR) images of the same scene and use them to reconstruct a high resolution (HR) image. However, two major computation problems need to be addressed, (1) the image registration and (2) the SR reconstruction. For the first hurdle is particularly difficult due to the spatially variant shifts estimation since objects in a scene are often at different depths. This poses a great computational challenge as the problem is NP complete. The multi-lenslet camera with a single focal plane provides us a unique opportunity to take advantage of the parallax phenomenon, and to relate object depths with their shifts. Thus we essentially reduced the parameter space from a two dimensional (x, y) space to a one dimensional depth space, which greatly reduces the computational cost. After registration, LR images along with estimated shifts can be used to reconstruct an HR image. A previously developed algorithm will be employed to efficiently compute for a large HR image in the size of 1024x1024.

7705-06, Session 2

Extraction of facility information for signature modeling

J. M. Cathcart, S. L. Otolorin, Georgia Institute of Technology (United States)

A major issue in constructing an accurate model of a structure from visible overhead imagery is the limited information available. This imagery typically provides high spatial resolution which can be used to provide accurate geometric dimensions, especially when supplemented with oblique photography and pre existing knowledge of the facility. As a

consequence, overhead images can be used to do rough reconstructions of the dimensions of a facility. Conversely, these sensors provide limited spectral information (typically three band color (RGB) imagery only). Thus accurate material classification becomes difficult. In this paper we will examine an approach to using RGB data provided from overhead imagery to create a geometric model of a cooling tower and to classify the exterior materials of that facility. Pixel and shadow analysis will be used to get the exterior dimensions of the structure; RGB signature analysis will be used to classify materials. We will compare our results to data from the actual facility. A quantitative assessment of the error will be presented. The second phase of our work will detail the improvements achievable by coupling more advanced multi-spectral visible band satellite imagery and LIDAR data to refine the facility information. While this research focuses on modeling a cooling tower from overhead imagery the nature of this method allows it to be extended to other facilities.

This work is supported under a grant from the Department of Energy.

7705-07, Session 3

Multispectral tactical integrated scene generation capability using satellite imagery

B. C. Smith, GSES/L-3 Services, Inc. (United States); T. Van, C. F. Coker, C. B. Willis, Air Force Research Lab. (United States); P. Destin, DCS Corp. (United States)

A multi-spectral tactical integrated scene generation capability using satellite imagery is currently available using a synthetic predictive simulation code developed by the Munitions Directorate of the Air Force Research Laboratory (AFRL/RWGGS). This capability produces multi-spectral integrated scene imagery from the perspective of a sensor/seeker for an air-to-ground scenario using geo-referenced U.S. Geological Survey (USGS) Digital Terrain Elevation Data (DTED) and satellite terrain imagery. This new synthetic scene generation capability generates geo-referenced radiance imagery from the perspective of a tactical sensor system whether it is stationary, on an Unmanned Aircraft System (UAS), or on a missile system. The produced imagery is spatially, spectrally, and temporally accurate. Based on the desired surveillance flight path and viewing angle, this capability has been interfaced with Microsoft-Virtual-Earth to extract terrain data of interest at the needed background resolution. This integrated application may be used to generate multi-spectral tactical scenarios to support Intelligence, Surveillance, and Reconnaissance (ISR). In addition, the scene generation capability can be used to generate imagery to support signal/image processing algorithm development and testing as well as support improvements in situational awareness, feature extraction (spatial, temporal, spectral), and discrimination. This paper will demonstrate the capability to generate synthetic geo-referenced radiance imagery for a multiple sensor platform system viewing the terrain as it maneuvers on a flight path in both the visible and infrared spectrum.

7705-08, Session 3

PerSEval phase I: development of a 3D urban terrain model for evaluation of persistent surveillance sensors and video-based tracking algorithms

D. M. Deaver, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

PerSEval is a modeling and simulation tool under development for end-to-end evaluation of airborne persistent surveillance imaging sensor systems. This class of sensor systems is characterized by having a wide coverage area over an extended period of time and operating in either visible or thermal infrared wavebands. Current operational systems are heavily used by image analysts for tracking vehicles or dismounted personnel, with an emphasis in urban areas of interest. Future persistent

surveillance systems will include automated ground target tracking algorithms to alleviate analyst workload. As an end-to-end tool, PerSEval will include dependencies on the scenario, platform, sensor, processing, and tracking algorithm. This paper will describe the overall PerSEval architecture as well as the first phase of development which focused on the creation of a three-dimensional urban terrain simulation appropriate for the evaluation of automated tracking algorithms.

7705-09, Session 4

Design, modeling, and simulations of nanophotonic devices for chip-scale optical interconnects

A. S. Sharkawy, O. Ebil, EM Photonics, Inc. (United States); M. J. Zablocki, D. W. Prather, Univ. of Delaware (United States)

In this talk we present and discuss several of the modeling challenges associated with using NanoPhotonic devices for the realization of chip-scale optical interconnects. As is well known, by removing metallic traces in high-speed systems, many signal integrity issues are reduced, or eliminated. In addition, photonic systems can require less power and offer higher efficiency. However, such challenge has been highly hindered by the inability to investigate numerically such structures with fine feature sizes due to the computational challenges conventional modeling tools are facing. Therefore, in order to harness the true potential on nanophotonic devices, computationally capable numerical tools implemented over the appropriate platforms are in great demand to face such challenges. Accordingly, this talk will present numerical studies, design and fabrication of various implementations of candidate photonic crystal devices for reconfigurable optically interconnected chip-scale networks.

7705-10, Session 4

Modeling multi-channel optical links using OptiSPICE for WDM systems

P. Gunupudi, T. J. Smy, Carleton Univ. (Canada); J. Klein, J. Jakubczyk, Optiwave Systems Inc. (Canada)

The efficient design of mixed optical/electrical communication systems are often limited by use of separate design tools for each energy domain. Increasing performance requirements are driving tighter integration between electrical and optical components using technologies such as Silicon based photonics. The use of such technologies will produce a need for fast single engine opto-electronics circuit simulation capabilities. Building on a previously presented framework for a single engine simulator OptiSPICE this paper will present models and techniques for modelling devices used in local area networks utilizing wavelength division multiplexing and implemented using Si photonics, single-mode fiber and Si based electronics.

This paper will detail time-domain models of various elements that form optical links in such a system. Detailed models based on physical rate equations will be presented for laser sources and electro-optic modulators. A single mode fiber model based on the Non-linear Schrodinger Equation and includes multiple channel effects will be presented. Finally, a model of an avalanche photo-diode using an electrical diode and a photo-current which is proportional to the optical intensity at the input will be described. Of primary concern in modeling of the photodiode is the correct implementation of the complex frequency response of the photo-current and this will be outlined in detail.

The final section of the paper will present results from a multi-channel optical link. The initial part of each channel is comprised of a laser source and driver, an optical gain/attenuation element and an electro-optical modulator driven by a bit stream generator. An optical multiplexing element is then used to merge the optical channels and this is connected to a single-mode fiber. At the end of the fiber an optical splitter is used with optical filters to de-multiplex the optical signal and finally a avalanche photo-diode and amplifier is used to terminate each channel.

7705-11, Session 4

Multi-transceiver simulation modules for free-space optical mobile ad hoc networks

M. Bilgi, M. R. Yuksel, Univ. of Nevada, Reno (United States)

This paper presents realistic simulation modules to assess characteristics of multi-transceiver free-space-optical (FSO) mobile ad-hoc networks. We start with a physical propagation model for FSO in mobile ad-hoc networking (MANET) context. We specifically focus on drop in power of the light beam and probability of error in the decoded signal due to a number of parameters (such as separation between transmitter and receiver and visibility in the propagation medium), comparing our results with well-known theoretical models. Then, we provide details on simulating multi-transceiver mobile wireless nodes in Network Simulator 2 (NS-2), realistic obstacles in the medium and communication between directional optical transceivers. We introduce new structures in the networking protocol stack at lower layers to deliver such functionality. At the end, we provide our findings resulted from detailed modeling and simulation of FSO-MANETs regarding effects of such directionality on higher layers in the networking stack.

7705-12, Session 4

The effects of electron temperature in terahertz quantum cascade laser predictions

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Quantum cascade lasers (QCL's) employ the mid- and far-infrared intersubband radiative transitions available in semiconducting heterostructures. Through the precise design and construction of these heterostructures the laser characteristics and output frequencies can be controlled. When fabricated, QCL's offer a lightweight and portable alternative to traditional laser systems which emit in this frequency range. The successful operation of these devices strongly depends on the effects of electron transport. Studies have been conducted on the mechanisms involved in electron transport and a prediction code for QCL simulation and design has been completed. The approach implemented utilized a three period simulation of the laser active region. All of the wavefunctions within the simulation were included in a self-consistent rate equation model. This model employed all relevant types of scattering mechanisms within three periods. Additionally, an energy balance equation was implemented to determine the temperature of electron distributions separately from the lattice temperature. This equation included the influence of both electron-LO phonon and electron-electron scattering. The effect of different modeling parameters within QCL electron temperature predictions will be presented along with a description of the complete QCL prediction code.

7705-13, Session 5

Analyzing the impact of data movement on GPU computations

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Recently, GPU computing has taken the scientific computing landscape by storm. Many legacy codes are being ported to GPU platforms to take advantage of the massive processing power modern GPUs present. When porting their code, researchers rely on a set of best practices that have been developed over the relatively few years that general purpose GPU computing has been available. One of the most widely held practices is that transfers to and from the GPU device must be minimized to achieve the best speedup over existing codes. This paper studies this concern and discusses under which circumstances it is appropriate and even advantageous to transfer freely to and from the GPU in the context of a case study on CULA, our library for dense linear algebra computation on GPU Among the topics to be discussed include the relationship between computation and transfer time for both synchronous and asynchronous transfers, as well as the impact that data allocations have on memory performance and overall solution time.

7705-14, Session 5

The risk-based verification, validation, and accreditation process

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This paper presents a risk-based Verification, Validation, and Accreditation (VV&A) process for Models and Simulations (M&S). Recently, the emphasis for M&S used to support DoD acquisition has been on basing the level of resources allocated to establishing the credibility of the M&S on the risks associated with the decision being supported by the M&S. In addition, DoD VV&A regulations recommend tailoring the V&V process to allow efficient use of resources. However one problem is that no methodology is specified for such tailoring processes.

The BMV&V has developed a risk-based process that implements tailoring of the VV&A activities based on risk. Our process incorporates MIL-STD 3022 for new M&S. For legacy M&S the process starts by first assessing the current risk level of the M&S based on the credibility attributes of the M&S as defined through its Capability, Accuracy and Usability, relative to the articulated Intended Use Statement (IUS). If the risk is low, the M&S is credible for application, and no further V&V is required. If the risk is medium or high, the Accreditation Authority determines whether the M&S can be accepted as-is or if the risk should be mitigated. If the Accreditation Authority is willing to accept the risks, then a Conditional Accreditation is made. If the risks associated with using the M&S as-is are deemed too high to accept, then a Risk Mitigation/Accreditation Plan is developed to guide the process. The implementation of such a risk mitigation plan is finally documented through an Accreditation Support Package.

7705-15, Session 5

Using simulation and virtual machines to identify information assurance requirements

S. B. Banks, Calculated Insight (United States); M. R. Stytz, Institute for Defense Analyses (United States)

The 2009 Cyber Report notes that DoD and government critical information systems are and will be targets of sustained attacks by sophisticated, well-funded, and persistent attackers. Operation in spite of cyberattack is possible only by using systems with sufficient inherent security. The obstacles to inherent security are determining the information assurance requirements for a DoD system, minimizing changes to its commercial software, incorporating new system and information assurance requirements in a timely manner with minimal impact, and insuring that interdependencies do not produce cyber attack vulnerabilities. In this paper, we discuss how simulation and virtual machines can be used to address all four issues.

This paper addresses the use of simulation and virtual machines to aid in the specification, testing, and assessment of software and IA capabilities required by DoD systems. Our objective was to determine how to capitalize upon commercial IA capabilities and expand upon them so that the DoD IA enhancements are logically and computationally separated from and independent of the commercial IA capabilities but complement and augment them. We also wanted to insure that the DoD system software could be rapidly changed with minimal impact on other system software.

The paper is organized as follows. The first section contains an introduction to the research area. The second section contains a background and survey of technologies we used. In the Third Section,

we discuss the virtual machine architecture and describe the simulation approach for identifying IA requirements and recommendations for using simulation for evaluating IA capabilities. Section Four contains a summary and suggestions for future work.

7705-16, Session 5

Thermal modeling under limited information conditions

J. M. Cathcart, S. E. Lane, Georgia Institute of Technology (United States)

By comparing information from a computer generated thermal model of a power plant to that obtained from thermal imagery one can estimate the operating state of the power plant. Many facilities of interest are in restricted areas so many aspects of the thermal models must be created solely from overhead imagery and the knowledge of the analyst. The choices made when modeling the interior of the cooling tower will directly influence the final radiances and apparent temperatures on the surface. Here we will address the error that is introduced in the modeling process due to this limited information. We will focus on a cooling tower that is located on the Savannah River National Lab (SRNL) site. A quantitative assessment of the error will be made by comparing thermal information from two models of the cooling tower. One model will be created from overhead imagery and typical construction data as found in the literature. A second model will be constructed using these data coupled with data collected onsite from the actual cooling tower; SRNL will provide assistance for this latter collection. The models will be created using Georgia Tech's first principles infrared signature generation tool, GTSIG, and other modeling tools. Radiance and temperature outputs of these two models will be compared to determine the relative error between the models. An assessment will also be presented on using this approach to the modeling of restricted access facilities.

This work is supported under a grant from the Department of Energy.

7705-28, Poster Session

A prioritization scheme of detector in intrusion detection model based on GA

P. Qiao, Harbin Univ. of Science and Technology (China)

The applications of Genetic Algorithm (GA) in Intrusion Detection have broad prospects. Various sorts of algorithms are emerging in an endless stream, improving the speed of algorithm convergence and overcoming the algorithm premature convergence are always the principal contradiction which we should seize. In connection with the two faults above, the optimization of detector redundancy, a new concept, and relevant content which bases on traditional theoretical model is lead into this paper. The Hybrid Intelligent Algorithm and the theory of Uniform Design Sampling (UDS) are used to redesign the crossover operation of genetic algorithm operator, the similar degree of cyber-chromosome in detector and relevant content are improved and correlate with detector redundancy. A new detector prioritization scheme is given on the basis of the combination of partial searching strategy and a new method to evaluate the data of redundancy. Simulation experiment presented that this scheme maintained the variety, high efficiency and sufficiency of detector. Thus this scheme can be certified that it has the better performance in search speed and global optimal ability and improve detection rate of detector and reduce false alarm rate to a certain degree.

7705-29, Poster Session

Integrating sensors into a distributed simulation environment

S. Gallant, C. Gaughan, C. Metevier, MATREX (United States)

Rapidly changing force compositions and new technologies create challenges for Modeling and Simulation (M&S) representation of current and future forces. The M&S systems should be flexible enough to allow for new force structures, platform types and information sharing TTPs to become an input to the system rather than software changes that require time and money to make and adjudicate. The MATREX program has developed a set of service-oriented applications to facilitate a flexible and dynamic implementation of the force structure's information sharing, fusion capabilities, human performance modeling and physics modeling responsibilities. These applications execute based on scenario inputs and allow the integration of thinly focused systems like sensors, C2 systems and physics models to be easily integrated based on selective technical integration design patterns. This service-oriented approach to distributed simulation can be a valuable lesson learned for the M&S community trying to integrate sensor models into a Systems of Systems (SoS) M&S environment.

7705-17, Session 6

On development of a VLSI circuit for impact source identification in ceramic plates

A. M. Dixit, H. Singh, Wayne State Univ. (United States); T. J. Meitzler, U.S. Army Research, Development and Engineering Command (United States)

Interest has been shown in the problem of real-time crack detection, crack extent measurement and the identification of the impact source causing the damage. A solution to the problem of impact source identification is presented using a signal processing technique employing piezoelectric sensors. In order to identify the source of the impact, the Fuzzy logic approach is suggested. Based on the FLA approach, a procedure to develop the rule base is given. The implementation of the rules is done using Hardware Description Languages (HDL) such as Verilog. The procedure from Verilog to VLSI implementation is suggested. FPGA implementation and testing of the suggested procedure is included. The problems for the future work on the development of VLSI identify the impact sources are given.

7705-18, Session 6

Realistic and efficient 2D crack simulation

J. Yadegar, X. Liu, A. Singh, UtopiaCompression Corp. (United States)

Although numerical algorithms for 2D crack simulation have been studied in Modeling and Simulation (M&S) and computer graphics for decades, realism and computational efficiency are still major challenges. We introduce a high-fidelity, scalable and efficient/runtime physics-based 2D crack/fracture simulation system that applies the highly scalable, efficient, and adaptive Peano-Cesaro triangular meshing/remeshing to model homogenous/heterogeneous shards/fragments structures. The recursive fractal sweep associated with the Peano-Cesaro triangulation provides efficient local multi-resolution refinement to any level of details. The generated binary decomposition tree provides efficient neighbor retrieval mechanism used for mesh element/cell splitting and merging with minimal memory requirements, this being essential for realistic 2D fragment formation. Upon load impact/contact/penetration, the system performs an analysis of plane stress/strain for affected cells. A number of factors including material elastic-plastic property, maximum tensile stress, and stress intensity factor (SIF) are all taken into account to produce the criteria of crack initialization, propagation, termination leading to formation of realistic fractal-like rubble. In addition to finite element analysis, the system utilizes an efficient hierarchical probabilistic based ontological reasoning to efficiently and realistically predict and simulate the crack/fracture propagation and termination. The ontology is generated through a combination of statistic and stochastic learning approach. Crack/fracture simulation has been conducted on various load impact/contact/penetration initial locations with different impulse scales. Results demonstrate that the proposed system has the capability

to realistically and efficiently simulate 2D crack phenomena (such as window shattering and shards generation) with diverse potentials in military and civil M&S applications such as training and mission planning.

7705-21, Session 7

Integrating botnet simulations with network centric warfare simulations

M. R. Stytz, Institute for Defense Analyses (United States); S. B. Banks, Calculated Insight (United States)

"Botnets," or "bot armies," are large groups of remotely controlled malicious software that attack computers, data, and networks. The botnet threat is significant because of the adoption of the network centric warfare (NCW) paradigm. A network centric force has the capability to share and exchange data among the force as needed. Botnets attack this capability, insert false information, and turn the network-centric capabilities against the organization. Because of the botnet threat we have undertaken research to characterize botnets, botnet operations and botnet simulation. Since network centric operations rely upon data and decision superiority, botnet defeat technologies should maximize the ability of networks and computers to execute their missions in spite of attacks, which can be assessed using simulation technology. This paper discusses the challenges to integrating bot simulations into larger simulation environments. A botnet simulation environment requires simulation of all botnet events and responses but actual attacks upon simulation systems must be avoided. To accurately portray cyber warfare involving botnets, two botnet activities must be simulated: 1) distribution of botnet commands and 2) the effect of botnet activity.

In the paper we discuss botnet technologies, their simulation, and their integration into larger simulation environments. The first section of the paper introduces the botnet technologies, botnet simulation challenge, and the reasons for its importance. The second section contains bot army background information. The third section contains a discussion of the techniques we developed for simulating botnet activities and integrating them into simulation environments. The fourth section contains a summary and suggestions for research.

7705-22, Session 7

Streaming video for distributed simulation

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Distributed simulation environments are increasingly using video to stimulate operational systems and their prototypical equivalents. Traditionally, this video has been synthesized and delivered by an analog means to consuming software applications. Scene generators typically render to commodity video cards, generate out of band metadata, and convert their outputs to formats compatible with the stimulated systems. However, the approach becomes hardware intensive as environment scale and distribution requirements grow. Streaming video technologies can be applied to uncouple video sources from their consumers thereby enabling video channel quantities beyond rendering hardware outputs. Moreover, metadata describing the video content can be multiplexed, thereby ensuring temporal registration between video and its attribution. As an application of this approach, the Night Vision Image Generator (NVIG) has been extended and integrated with distribution architectures to deliver streaming video in virtual simulation environments. Video capture hardware emulation and application frame buffer reads are considered for capturing rendered scenes. Video source to encoder bindings and content multiplexing are realized by combining third party video codec, container, and transport implementations with original metadata encoders. Readily available commercial and open source solutions are utilized for content distribution and demultiplexing to a variety of formats and clients. Connected and connectionless distribution approaches are discussed with respect to latency and reliability. Client side scalability, latency, and initialization issues are addressed. Finally, the solution is applied to tactical systems stimulus and training, showing the evolvement from the analog to the streamed video approach.

7705-23, Session 8

Warfighter decision making performance analysis as an investment priority driver

D. J. Thornley, Imperial College London (United Kingdom); D. Dean, Defence Science and Technology Lab. (United Kingdom); J. C. Kirk, Honeywell Technology (United States)

Estimating the relative value of alternative training, tactics and procedures (TTP) and information systems requires measures of the costs and benefits of each, and methods for combining and comparing those measures. The NATO Code of Best Practice on Command and Control Assessment explains that decision making quality would ideally be best assessed on outcomes. Lessons learned in practice can be assessed statistically to support this, but experimentation with alternate measures in live conflict is undesirable. To this end, the development of practical experimentation to parameterize effective constructive simulation and analytic modelling for system utility prediction are desirable. The Land Battlespace Division of DSTL has modeled human development of situational awareness to support constructive simulation by empirically discovering how evidence is weighed according to circumstance, personality, training and briefing.

The human decision maker provides the backbone of military engagements because of uncertainty that cannot be automatically resolved. To develop methods for assessing how best to prepare and inform the decision maker, we are developing componentized timed analytic stochastic model components and instruments as part of a framework to support quantitative assessment of intelligence production and consumption methods in a human decision maker-centric mission space. In this paper, we formulate an abstraction of the human intelligence fusion process from DSTL's INCIDER model to include in our framework, and synthesize relevant cost and benefit characteristics.

7705-24, Session 8

Individual warfighter effectiveness and survivability in a CBRN threat environment

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The effort described in this paper attempts to enhance the state-of-the-art to model high-fidelity (hi-fi) dismounted infantry interactions with a realistic Chemical, Biological, Radiological, Nuclear (CBRN) hazard. There is limited CBRN Modeling & Simulation (M&S) capability for research, training and doctrine development. Although numerous ground and plume hazards simulations exist, few model the entire problem space.

To this end, the following three hi-fi simulations are being federated: 1) The Infantry Warrior Simulation (IWARS); 2) The Command Control, and Communications Human Performance Model (C3HPM); and, 3) The CBRN Simulation Suite via High Level Architecture (HLA) using the Modeling Architecture for Technology, Research and EXperimentation (MATREX) architecture.

The goal of this federation is to provide an integrated capability that will allow analysis of CBRN sensors and Warfighter protective equipment in the context of a complex battlefield environment with dismounted infantry missions/tactics. The IWARS provides representation of dismounted entities and their decisions/physical tasks in a battlefield environment. The C3HPM provides task degradation data due to presence of various CBRN threats and due to wearing of CBRN protective equipment. The CBRN Sim Suite provides dynamic threat events/propagation, high fidelity CBRN sensor representations with tactical message output,

CBRN injury based on exposure dosage/concentration and entity protection.

This paper will describe the methodology of the integration, detailing how the models were expanded, what interactions are passed and how. It will also present simulation results of a representative CBRN scenario detailing mission effectiveness. Finally, it will describe the applications to research, training and doctrine development.

7705-25, Session 8

Simulating effectiveness of helicopter evasive maneuvers to RPG attack

D. Anderson, D. G. Thomson, Univ. of Glasgow (United Kingdom)

The survivability of helicopters under attack by ground troops using rocket propelled grenades has been amply illustrated over the past decade. Given that an RPG is unguided and it is infeasible to cover helicopters in thick armour, existing optical countermeasures are ineffective - the only feasible approach to improving platform survivability is to compute an evasive manoeuvre. In this paper, an RPG/helicopter engagement model is presented. Six degree-of-freedom nonlinear models of the RPG-7 grenade in flight and a Lynx helicopter are integrated into a MATLAB GUI. The helicopter is assumed to be carrying an appropriate suite of missile warning cameras to provide bearing information of the RPG warhead with respect to the helicopter centre-of-gravity. A projection of the helicopter geometry is overlaid onto the MAWS image plane allowing an estimated impact point to be computed in image space. Using this information, manoeuvre profiles are defined in the MAWS image plane using a combination of a suite of local maximum acceleration vectors and critical component locations on the platform, which must be avoided to minimise the vulnerability of the helicopter should a hit be unavoidable. Once the optimal evasion trajectory has been selected, the required control inputs to manoeuvre the aircraft are then computed using inverse simulation techniques. Assessments of platform survivability to several engagement scenarios are presented.

7705-26, Session 8

SOA approach to Battle Command to Simulation interoperability

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NVESD is developing a Sensor Data and Management Services (SDMS) Service Oriented Architecture (SOA) that provides an innovative approach to achieve seamless application functionality across simulation and battle command systems. In 2010, CERDEC will conduct a SDMS Battle Command to Simulation demonstration that will highlight the SDMS SOA capability to couple simulation applications to existing Battle Command systems. The demonstration will leverage RDECOM MATREX simulation tools and TRADOC Maneuver Support Battle Laboratory Virtual Base Defense Operations Center facilities. The battle command systems are those specific to the operation of a base defense operations center in support of force protection missions. The SDMS SOA consists of four components that will be discussed. An Asset Management Service (AMS) will automatically discover the existence, state, and interface definition required to interact with a named asset (sensor or a sensor platform, a process such as level-1 fusion, or an interface to a sensor or other network endpoint). A Streaming Video Service (SVS) will automatically discover the existence, state, and interfaces required to interact with a named video stream, and abstract the consumers of the video stream from the originating device. A Task Manager Service (TMS) will be used to automatically discover the existence of a named mission task, and will interpret, translate and transmit a mission command for the blue force unit(s) described in a mission order. JC3IEDM data objects, and software

development kit (SDK), will be utilized as the basic data object definition for implemented web services.

7705-27, Session 8

A simulation approach to a virtual base defense operating center

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The TRADOC Maneuver Support Center is the Army Center Of Excellence for Protection and in turn, has the mission to support Force Protection (FP) doctrine development. The Maneuver Support Battle Lab was tasked with refining doctrinal solutions to provide enhanced FP (SOPs, TTPs, etc.), identifying the information needed on the Common Relevant Operating Picture and identifying the CONOPS that will provide enhanced FP with an emphasis on unmanned ground vehicles (UGVs) with lethal and non-lethal capabilities. A modeling & simulation (M&S) architecture was constructed to support a Force Protection Joint Experiment (FPJE) aimed at these issues. The use of Modeling and Simulation was especially important due to the cost and availability of soldiers for live experimentation. Moreover, the Chemical, Biological, Radiological, and Nuclear (CBRN) aspect was best represented via M&S to ensure a realistic depiction.

The simulation architecture included a force-on-force simulation, a CBRN simulation, a desktop UGV Advanced Concepts Research Tool and a sensor controller. This simulation architecture stimulated actual Command & Control (C2) systems including the Joint Battlespace Command and Control System and the Joint Warning and Reporting Network. These C2 systems, along with sensor video feeds from UGVs, were used by Battle Captains for situational awareness of the battlefield while conducting the experiment. The result was a Virtual Base Defense Operating Center able to exercise FP CONOPS and doctrine.

This paper will describe the design of the simulation architecture and associated C2 systems used to conduct the FPJE. It will also provide results of the FPJE and how those are driving FP doctrine development.

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7706-01, Session 1

Cross-layer protocol design for QoS optimization in real-time wireless sensor networks

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The distributed and collaborative interactions among autonomously deployed nodes of a wireless sensor network (WSN) focus on the cooperative processing of data from multiple types of sensors to satisfy common mission objectives. In contrast to information flows in a mobile ad hoc network (MANET), sensor data originate at resource-constrained nodes, located at the periphery of the WSN, and are successively processed at intermediate nodes via aggregation (fusion) based on information-theoretic measures of correlation and output as information in a forward direction toward the sink (decision) nodes. "Multimedia" services in a MANET are analogous to multiple types of raw sensor inputs, e.g., audio, seismic, chemical, thermal, video, etc., to the WSN. The metrics of quality of service (QoS) for each sensor type in the WSN can be associated with metrics for multimedia that describe the quality of fused information, e.g., throughput, delay, jitter, packet error rate, information correlation, etc. These QoS metrics are typically set at the highest, or application, layer of the protocol stack to ensure that performance requirements for each type of sensor data are satisfied. Application-layer metrics, in turn, depend on the performance of the lower protocol layers: presentation, session, transport, network, data (link), and physical. In a departure from previously published research, the dependencies of the QoS metrics on the performance of the higher layers of the protocol, together with that of the lower three layers, are the basis for a comprehensive approach to QoS optimization for the multiple sensor types in a general WSN model. Only the presentation layer of the protocol stack is absent from the development to be discussed in a future exposition on cross-layer protocol design for security. Cross-layer design must account for the distributed power consumption at energy-constrained routes and their constituent nodes.

Following earlier analytical development by the author, the cross-layer interactions in the WSN protocol are represented by a set of concatenated protocol parameters and associated resource levels. In this work the set of parameters is expanded to include factors identified with the session and transport layers. In the mathematical foundations of the approach, the "best" cross-layer designs to achieve optimal QoS are established by applying the general theory of martingale representations to the parameterized multivariate point processes (MVPPs) for discrete random events occurring in the dynamic WSN. The representations are used to develop the transient characteristics on which optimality conditions for the cross-layer designs are derived. Functional dependencies of application-layer metrics are expressed as mappings from the set of concatenated protocol parameters of the lower layers. Conveniently, many of the metrics can be represented as weighted linear expressions of the components comprising the defined "state" of the network. A protocol design for optimal QoS adapts to the transient network conditions and available resource levels to achieve the best performance for each service type active in the WSN. Adaptive control of network behavior through the protocol design is realized through the stochastic conditional rates of the parameterized MVPPs. The cross-layer protocol parameters for optimal QoS are determined in terms of solutions to stochastic dynamic programming conditions derived from models of transient flows for different sensor data and fused information over a finite time horizon.

For a general wireless network of many nodes, closed-form solutions to the system of stochastic dynamic programming conditions are, if not impossible, difficult to determine. Fortunately, the conditions that define many WSNs, in particular, the grouping of sensor nodes into clusters, the feed-forward nature of data fusion at intermediate nodes, and normally non-empty processor queues of data packets at nodes, result in significant simplifications of the stochastic differential equations that describe parameterized network dynamics. These simplifications, in turn, lead to iterative, computationally tractable solutions to the dynamic programming conditions that determine QoS-optimal protocol parameters. Moreover, if the observed history is limited to the last fixed N transitions in the network, a new marked Markov process can be derived from the original WSN state process. The resulting simplified dynamic programming conditions for the QoS-optimal protocol parameters lead to cross-layer policies that are also Markov. Special WSN circumstances are considered: bounded and enclosed environments containing fixed targets that are monitored by wireless sensors of multiple types located at a small number of stationary nodes; open environments containing fixed targets, exhibiting range-bound, multi-sensory phenomena and randomly located according to a known stochastic spatial distribution, that are monitored by stationary wireless sensors of multiple types; or open environments containing mobile targets, displaying range-bound, multi-sensory phenomena, that are monitored by moving wireless sensors of multiple types with relative sensor-to-target distances that follow deterministic or random equations. It has been shown that, for these special cases, closed-form solutions to the system of dynamic programming conditions with Markov assumptions can be found to yield QoS-optimal cross-layer protocols for specific metrics. Numerical examples for the three aforementioned special cases are computed for WSNs of a small number of nodes, using initial values from the lower protocol layers of the Zigbee (IEEE 802.15.4), IEEE 802.11n, and mobile WiMAX (IEEE 802.16) standards and from the higher layers of proposed mobile multimedia networks.

7706-02, Session 1

Design of a wireless sensor network with nanosecond time resolution for mapping of high-energy cosmic ray shower events

M. P. Frank, Florida A&M Univ. (United States); S. Junnarkar, Brookhaven National Lab. (United States); R. H. O'Neal, Florida A&M Univ. (United States)

We describe the system architecture and selected aspects of the detailed design for a low-cost, low-power wireless sensor network we are developing for high time-resolution (nanosecond-scale) detection of atmospheric particle showers produced by ultra-high-energy cosmic rays, for purposes of gathering information on shower bearing and source location at sites where a hard-wired connection to each sensor may be inconvenient. An enclosed assembly of a scintillator block and a photomultiplier tube (PMT) is used as the front-end particle sensor. We achieve high-precision wireless timing synchronization using periodic wide-angle, high-intensity optical sync pulses emitted from centralized light-emitting-diodes (LEDs) overdriven at high current (30 A) in short (4 ns) bursts, resolvable in ambient light conditions at multi-meter distances by a high-speed avalanche photodiode (APD) based optical receiver at each node. PMT pulse waveforms are digitized & precise timing information extracted on a Field Programmable Gate Array (FPGA) using a Time-over-Threshold (ToT) and TDC based Analog to Digital Converter (ADC) developed by BNL. Real-time analysis, aggregation & visualization of data is performed on a central server which receives timestamped, digitized PMT pulse waveforms from the sensor nodes via a Wi-Fi network. Apart from a few simple custom printed circuit boards (PCBs), all components in the system design are readily-available commercial off-the-shelf (COTS) parts. Total cost per sensor node is a few thousand dollars, with total power consumption per node under 1 Watt, well suited to, e.g., solar-powered installations at remote field locations.

7706-03, Session 1

Clustering-based learning for passive intrusion detection in mobile wireless networks

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The rapid advancements in wireless technologies are leading to a future where wireless networks will become more pervasively deployed. The large-scale wireless sensing data collected from mobile wireless networks can be used for detecting targets (e.g., enemies in tactical fields), and further facilitating real-time situation awareness in Army's network-centric warfare applications such as intrusion detection, battlefield protection and emergency evacuation. In our work, we focus on exploiting Received Signal Strength (RSS) obtained from the existing pervasive wireless infrastructures for performing intrusion detection when the intruders or objects do not carry any radio devices. This is also known as passive intrusion detection. Passive intrusion detection based on the RSS data is especially attractive as it reuses the existing wireless environmental data without requiring a specialized infrastructure. Furthermore, the RSS data is available at any time, which makes it possible to detect and locate people under emergency situations in a timely manner. We propose a clustering-based learning approach for passive intrusion detection in mobile wireless networks. Specifically, our detection scheme utilizes the RSS and an unsupervised clustering learning method for passive intrusion detection. By utilizing the clustering method to analyze the changes of RSS at multiple devices collaboratively, we can determine whether there is a presence of intrusions as well as identify different type of intrusion patterns. Our experimental results using an IEEE 802.15.4 (Zigbee) network in a real office environment show that our clustering-based learning can effectively diagnose the presence of intrusions and distinguishing different types of intrusion patterns.

7706-04, Session 1

Bio-inspired secure data mules for medical sensor network

R. S. Muraleedharan-Sreekumaridevi, L. A. Osadciw, Syracuse Univ. (United States)

The recent advancements in wireless and nano technology have led to the development of sensor based applications such as health monitoring, emergency responder, border protection, etc. Medical sensor network consist of heterogeneous nodes, wireless, mobile and wired, and has varied functionalities. In a dynamic medical environment, different devices from varied companies are attached on a patient, and are required to sense information from the patient. The detected information is required to be communicated to the access point (Nurse Station or database). Since, the number of sender and receiver are dynamic, and the information flow is unpredictable. A robust and resource efficient bio-inspired data mule that can communicate information securely with high successful data delivery, and reduced latency and response time is preferred.

The bio-inspired algorithm can be used to solve any NP hard communication problem and possesses characteristics such as robustness and versatility. Data mules search for patterns, combines correlated data and makes decision for global region of interests in a decentralized manner. Hence, the reactive approach is an apt solution for a dynamically changing environment. The data mule is mission-oriented and dependent on orthogonal and controllable parameters; therefore a detailed analysis of the application is important for choosing the performance metrics. The proposed approach promises features such as low computation overhead, robustness, versatility, resource efficient and reliability.

7706-05, Session 1

Frame aggregation and optimal frame size for p-persistent based next-generation WLANS

A. Ahmad, K. B. Anna, M. A. Bassiouni, Univ. of Central Florida (United States)

The next Generation IEEE 802.11n is designed to improve the throughput of the existing standard 802.11. It aims to achieve this by increasing the data rate from 54 Mbps to 600 Mbps with the help of physical layer enhancements. Therefore, the Medium Access Layer (MAC) requires improvements to fully utilize the capabilities of the enhanced 802.11n physical layer.

In this paper, we present the performance evaluation results of two frame aggregation techniques viz., MAC Protocol Data Unit Aggregation (A-MPDU) and MAC Service Data Unit Aggregation (A-MSDU) and study the performance impact when the two schemes are incorporated in a p-persistent based 802.11n. Our performance tests cover a wide range of traffic loads and included both the the uni-directional and bi-directional transmission modes. The simulation results have shown that the two schemes achieve consistent performance improvement. Details of the performance tests and comparison results between the two schemes will be given in the full paper.

We also plan to incorporate the Optimal Frame Size Adaption, Randomized Frame and Fixed Frame algorithms proposed in [1] for the standard 802.11 in our p-persistent 802.11n and evaluate their performance.

Analytical modeling of 802.11n is another important research activity in our group. We have previously presented an analytical model for the p-persistent 802.11 standard protocol [2]. In the full paper, we present an approach for extending this analytical model to the case of p-persistent 802.11n with consideration to packet losses due to both collisions and channel errors.

[1] Yuxia Lin; Wong, V.W.S., "WSN01-1: Frame Aggregation and Optimal Frame Size Adaptation for IEEE 802.11n WLANs," Global Telecommunications Conference, 2006. GLOBECOM '06. IEEE , vol., no., pp.1-6, Nov. 27 2006-Dec. 1 2006

[2] Anna, K. and Bassiouni, M. 2008. A new framework for QoS provisioning in WLANS using p-persistent 802.11 MAC. Comput. Commun. 31, 17 (Nov. 2008), 4035-4048.

7706-06, Session 2

A novel approach to space-time-frequency coded MIMO-OFDM over frequency selective fading channels

M. Al-Mahmoud, M. D. Zoltowski, Purdue Univ. (United States)

This paper proposes a space-time-frequency coding scheme for MIMO-OFDM that achieves full rate for an arbitrary number of antennas with complex-valued information symbols. In addition, the proposed scheme provides a very high level of diversity with relatively low complexity. In the new scheme, the spatial and frequency spreading is followed by a temporal spreading that facilitates simple separation of the respective signals sent by the various transmit antennas. This temporal spreading enables perfect separation of the superimposed transmit signals at the receiver {bf prior} to channel estimation. The Local Maximum Likelihood (LML) method of Rugini et al is employed to further reduce complexity. Simulations are presented demonstrating the efficacy of

the new scheme. For example, for cases where an Orthogonal Space-Time Block (OSTBC) code exists, the new scheme is shown to provide the same full-diversity as the OSTBC. Again, though, the new scheme is applicable for an arbitrary number of transmit antennas and complex-symbol constellations.

7706-07, Session 2

Space-time processing for MIMO-OFDM using DFT-based complementary sequences

C. C. Lau, M. D. Zoltowski, Purdue Univ. (United States)

In this paper, a new method of space-time processing is proposed for Orthogonal Frequency Division Multiplexing (OFDM) using complementary sequences derived from the rows of the DFT matrix. The autocorrelative properties of the complementary sequences allows multiple complex data signals at the transmitter with an arbitrary number of antennas to be perfectly separated at the receiver without prior channel knowledge while achieving full-rate. This new method is proposed and derived for multiple MIMO-OFDM systems with multipath fading; at the receiver, symbol estimation is effected via maximum likelihood estimation (ML).

7706-08, Session 2

Power amplifier distortion effects on the receive performance of single-carrier and multiple-carrier waveforms

J. W. Nieto, Harris Corp. (United States)

This paper will investigate what effect power amplifier distortions have on the receive performance of single-carrier and multiple-carrier waveforms.

7706-09, Session 2

Performance evaluation of coded-OFDM system using iterative decoding of concatenated GLDPC and Reed-Solomon codes

A. M. Abdelaal, Egyptian Air Force (Egypt)

Recent mobile communication systems require both high quality and high-bit-rate transmission. OFDM has been proven as an attractive technique for the high-bit-rate data transmission in a multipath environment that causes inter symbol interference (ISI). The ISI in OFDM can be eliminated by adding a guard interval. Therefore, when each subchannel is taken into consideration, it apparently undergoes flat fading even if the original wideband signal suffered frequency selective fading. Moreover, the distorted symbols can be corrected using error-correcting codes

In the last few years, Low-Density Parity-Check (LDPC) codes have attracted much attention particularly in the field of coding theory. It has a performance very close to the Shannon limit. As a trade off between decoding complexity and performance Generalized LDPC (GLDPC) has been introduced. It uses Soft-In-Soft-Out (SISO) decoding base on sub-optimal Chase-2 algorithm rather than a probability propagation algorithm; sum-product algorithm or belief propagation algorithm.

This work introduces a novel approach by using the Reed-Solomon codes as an outer code followed by an inner GLDPC. Both codes will be decoded using the Chase algorithm. The first scheme will use Soft-In-Hard-Out (SIHO) decoding for Reed-Solomon codes, while the second scheme will use SISO with joint iterative decoding. Simulation results, for different block sizes of OFDM, over AWGN and Raleigh fading channel will be used to evaluate the performance of GLDPC and the concatenated Reed-Solomon GLDPC.

7706-10, Session 3

Joint approximation of localization and path exponents in a RSS system

U. M. S. Tureli, D. Kivanc-Tureli, West Virginia Univ. (United States)

Indoor localization is increasingly important to support a variety of new applications and networking paradigms. Recent advances in wireless hardware and protocols, have enabled easy deployment of wireless nodes which already have a receiver signal strength indicator (RSSI) built in. RSSI measurements can be mutually performed over a network of N nodes, such that $Nx(N-1)$ measurements are available to mitigate measurement errors.

A radio frequency communication wireless system can be localized using received signal strength measurements for indoor applications. Collaborative techniques such as multidimensional scaling have been shown to overcome significant ranging errors on a single floor. However, such techniques are highly sensitive to modeling mismatches including transmit power variation and path loss exponent especially when the signal goes through additional attenuation through floors indoors. When sources path loss coefficients are known a priori, wMDS and similar algorithms can mitigate large measurement errors. On the other hand, maximum likelihood estimator (MLE) can jointly estimate path loss coefficient and location. MLE is based on geometry, and is not particularly suited to deal with outliers caused by NLOS environment. In previous works, it was proposed to use MLE with all combinations of sensor measurements but this gets rather computationally intensive when the network size scales up.

In this paper, we examine an iterative joint estimator which jointly estimates location and path loss exponent for different users. The estimator uses MDS to get initial estimates to start the search over the parameter space, and parameterizes more than one path loss exponent without loss of generality to unique path loss for each source. Numerical results shown superior performance in three dimensions when multiple floors are considered with different path losses.

7706-11, Session 3

Efficient wireless location detection system

S. Alsharif, M. S. Alam, Univ. of South Alabama (United States)

Over the past few years, several wireless location detection algorithms have been developed. An effective solution for CDMA-based wireless communication system is yet to be found. In this paper, a position location estimation technique for CDMA wireless communications system is proposed. The proposed technique utilizes the Chan-Ho method for solving the hyperbolic model, which provides faster solution to the hyperbolic model and does not suffer from the convergence problem. The performance of the proposed position location technique has been tested by considering different system parameters, such as channel noise and variable position of the user. Test results show that the proposed position location technique can successfully determine the position of a wireless user under various challenging scenarios.

7706-12, Session 3

A cellular neural localization and tracking system

M. M. Ahmad Al-Bajari, Technische Univ. Berlin (Germany); J. Ahmed, Mosul Univ. (Iraq)

Local Positioning System (LPS) is a system that is used for positioning Mobile Stations (MSs) located in a local cellular network, for different purposes, such as, military and civil applications. Real-time tracking systems are also needed to track multiple desired signals that change their directions continuously and rapidly.

In this paper, Adaptive Antenna Array (AAA), is used in the BSs instead of the traditional sectored antennas. The system built in this work uses AAA based on the Radial Basis Function Neural Network (RBFNN) in the BSs. The RBFNN is used to estimate the AOA of the received signal(s) depending on computed by a signal-processing unit that precedes the RBFNN.

The Performance of the proposed system is experimentally evaluated in a variety of numbers of signal sources and positions. The simulation results show that the developed location system has high reliability and accuracy with an average localization error range below few meters.

7706-13, Session 3

Target localization in moving radar platform exploiting range and Doppler information through semidefinite relaxation

Y. Zhang, J. Liu, M. G. Amin, Villanova Univ. (United States)

Moving radar platforms form synthetic apertures for effective target localization. One of the important target localization techniques is to multilaterate the position of a target based on the own positions of the radar and the range estimates obtained from two-way time-of-flight observations. In practical applications, the radar positions as well as the range estimates are subject to error due to maneuvering as well as measurement noise. Previous works have shown that, by incorporating the semidefinite relaxation techniques which permit the use of convex optimization approaches to solve a large class of nonconvex estimation problems, improved target location estimates can be achieved over those obtained from conventional techniques, such as least square methods. In some radar applications, on the other hand, it may be advantageous to incorporate the Doppler measurements. Doppler information is particularly helpful when narrowband signal waveforms are used in the radar system. In this paper, we consider the problem of target localization based on the range and Doppler estimates obtained at multiple radar locations, where such information as well as the radar locations are subject to certain random errors. Semidefinite relaxation is applied to formulate convex solutions for this problem. Simulation results are provided to demonstrate performance improvement of the proposed approach compared to the least square method and semidefinite relaxed convex optimization techniques without utilizing the Doppler information.

7706-14, Session 3

Iterative MMSE cooperative localization with incomplete pair-wise range measurements

S. Xi, M. D. Zoltowski, Purdue Univ. (United States); L. Dong, Western Michigan Univ. (United States)

Cooperative localization, where nodes' coordinates are simultaneously estimated using pair-wise range measurements between each pair of nodes, is an important localization technique. We have proposed an iterative minimum-mean-square-error (MMSE) cooperative localization algorithm, which achieves better root-mean-square-error (RMSE) performance than existing classical estimators. In this work, we further study this algorithm in the scenario where pair-wise range measurements are incomplete, that is, pair-wise range measurements between certain pair of nodes are missing. The received signal strength (RSS) measurement is adopted.

Two situations with incomplete range measurements are considered. In one situation, some RSS measurements are missing because they drop below a detectable threshold due to the long distance between the corresponding pair of nodes. As shown by the simulation results, performance degradation due to certain number of missing RSS measurements is neglectable. Motivated by this observation, we propose to improve the computation efficiency of the iterative MMSE algorithm by intentionally excluding small RSS values that correspond to those nodes which are far away and thus carry little weight on the estimation results. How to determine the threshold to decide if a RSS value is too small is

also provided. In another situation with incomplete measurements, there may exist hostile interference (jamming) or large-scale shadow fading that causes some pair-wise measurements undetectable. In this situation, any pair of nodes, even nodes that are close to each other, is possible to be affected. We study how the iterative MMSE algorithm work in this situation, analyze reasons and provide solutions.

7706-15, Session 4

Path loss measurements and comparisons for 433 MHz, 869 MHz, and 1249 MHz wireless systems within multi-floored buildings

I. F. Isnin, M. Tomlinson, M. Z. Ahmed, M. A. Ambroze, Univ. of Plymouth (United Kingdom)

In this paper, an extensive set of propagation path loss measurements within multi-floored buildings for 433 MHz, 869 MHz and 1249 MHz are presented.

Parameter statistics of two indoor path loss prediction models, Log-Distance and Floor Attenuation Floor models, are derived from the measurement data within three different buildings.

Buildings were chosen with typical features such as rectangle footprint, square footprint and the existence of an atrium in the building, respectively.

Comparisons are made between the different frequencies and building features.

It is found that 433 MHz carrier frequency is more robust for coverage areas that involving penetration of floors within the building.

The 1249 MHz carrier frequency is found to be best in guided propagation environments and LOS environments that exist in some areas within buildings.

It is also found that buildings with a square footprint have higher path losses compared to buildings with a rectangular footprint.

Buildings with an indoor atrium are found to have lower path losses than buildings without an atrium when considering multi-floor transmission.

Path loss prediction within buildings with an indoor atrium is refined by considering the types of transmission, LOS and NLOS, that occur between transmitter and receiver.

It is shown that using this refinement, better prediction accuracy is obtained.

New attenuation factors are derived and standard deviations of path loss prediction error are reduced as a result.

7706-16, Session 4

Sparsity based interferometric imaging

R. M. Rao, U.S. Army Research Lab. (United States); S. A. Dianat, Rochester Institute of Technology (United States)

A nonlinear beamforming technique is introduced for interferometric imaging. Correlative interferometry of finite extent sources suffers from poor resolution and spurious artifacts. We pose the reconstruction as an optimization problem with a sparsity constraint on the source in a projected space. The correlative interferometry problem is reformulated as an inverse problem of the form y= Rx where R is a matrix transforming the object to the spatial autocorrelation, y is the autocorrelation estimated from the sensor measurements, and each entry in the vector x represents the presence of an object at a given location. Since the sources are sparse the entries in x will mostly be zero or insignificant. Therefore, we minimize an L2 constraint on the reconstruction with an L1 constraint on the source locations. This constraint problem is a convex optimization which will provide a sparse solution. The non-zero values of x above a threshold represent the location of the object.

7706-17, Session 4

Wireless mesh networked radios optimized for UGS applications

W. Calcutt, J. Williams, B. M. Jones, McQ, Inc. (United States)

Wireless mesh networked (WMN) radios have been applied to unattended ground sensor (UGS) applications for a number of years. However, adapting commercial off-the-shelf (COTS) WMN protocols and hardware for UGS applications has not yielded the desired performance because of compromises inherent to these existing radios. As a leading provider of UGS systems, McQ Inc. has been developing custom WMN protocols and radio hardware that are adapted specifically for the unique scenarios of the UGS situation. This paper presents the McQ designs, the tradeoffs made in developing the designs, and test and performance results.

7706-18, Session 4

Method and system for early warning based on sensor data from mobile devices using single unit and micro array capability

G. Singh, T. Anderson, P. J. Young, N. C. Rowe, Naval Postgraduate School (United States)

Small unit military operations are often fast-paced and resource constrained, and can often end-up in situations where the safety of the unit as a whole rests on the shoulders of a watchful team member. Fatigue may inevitably degrade the team's situational awareness. In such situations, the team runs the risk of being ambushed by the enemy leading to loss of life and property. Such situations are also common in distributed warfighting where small units conduct operations in remote, austere environments where security is completely organic. The demand for technology enhanced situational awareness is warranted at both the unconventional and conventional unit level.

We research a light-weight, low-power non line-of-sight monitoring capability to alert on human and vehicle, and machinery in the local area. This situational awareness capability is implemented using existing equipment and without introducing significant additional weight, uses very little power, and is easy to install and operate.

We present several embodiments of a system that achieves this capability by using the latest COTS smartphones augmented with simple extensions. This system is able to detect the presence of suspicious entities (both people and machines) several meters to tens of meters away and immediately provides alerts to the tactical operator. Our primary sensing mechanism in the system is seismic and is implemented using the accelerometers built in to the latest smartphones. We create a network of smartphones using bluetooth to provide a robust surveillance capability.

7706-19, Session 4

Performance of concatenated convolutional codes

F. C. Kellerman, Harris Corp. (United States)

This paper will evaluate the performance and feasibility of convolutional codes when combined with differential phase shift key modulation. Prior work by Lo and Martin 2008 and others have shown excellent results utilizing linear block codes iteratively in conjunction with DPSK. Also further experimentation will be performed to modify the system to utilize coherent modulation and compare that with the DPSK system. Results for block error rate and bit error rates will be demonstrated.

7706-33, Poster Session

High-power interference suppression via reduced complexity adaptive blind beamforming

G. Okamoto, C. Chen, Adaptive Communications Research, Inc. (United States)

This paper evaluates an adaptive beamforming solution which addresses the significant problem caused by high-power transmitters located in close proximity to users. Current solutions are overwhelmed by the rapid increase in number and variety of strong interference sources. This smart antenna blind beamforming algorithm requires less computational complexity than standard algorithms, making it feasible to be added to current and next-generation systems, and provides a highly adaptive and reliable interference-resistant communications environment. Simulations show that ACRi's high-power interference mitigation solution automatically nulls jamming signals that are 20 dB to 40 dB stronger than the user signal. The results show that ACRi's new beamformer achieves close to the theoretically best performance obtained by algorithms such as MVDR that assume the spatial information of the user and interference signals are known (which may not be feasible when high-power interference is present and the user is mobile), which is excellent because ACRi's algorithm requires significantly less computational complexity and does not require the spatial information to be known in advance for the user or the interference signals. Systems with a limited number of antennas are evaluated because legacy and current generation systems have as little as two antennas.

7706-34, Poster Session

Tracking and interference suppression performance for the minimal computational complexity non-Eigen decomposition beamformer

G. Okamoto, C. Chen, Adaptive Communications Research, Inc. (United States)

This paper evaluates tracking and interference suppression performance for the ultra low complexity Non-Eigen Decomposition (NED) blind beamforming algorithm. Current blind beamforming algorithms require too much computational resources for them to be used by ground and air robotic systems and other systems with limited available computational power. This paper focused on the ultra low complexity NED beamforming algorithm for adaptive interference mitigation. NED does not rely on the eigenvalues and eigenvectors used by conventional algorithms, and requires significantly less computations, with a total computational load of O(4M-4) per snapshot for a system with M receiving antennas by approximating the cross correlation vector of the received signals in the reference and other antennas. This technique requires neither a training sequence nor an assumption of incoherency among impinging signals. By significantly reduces the computational requirements for beamforming, NED makes it possible for robotics and other systems to achieve the advantages of beamforming-such as enhanced reliability, increased range, resistance to co-channel interference signals, increased throughput and capacity, and extended battery life. Tracking ability determines what types of applications and scenarios a technique is applicable for, particularly important in mobile wireless systems such as the target applications identified for NED (ground robots, unmanned aerial vehicles, and mobile phone handsets). Simulation results show that the DOA estimated by NED is almost identical to the true DOA even when the user moves extremely quickly, with NED's fast convergence rate (only 4 iterations needed in the highest mobility case) also evident. The high angular movement between samples corresponds to user speeds ranging from 31 km/h to 124,000 km/h if the distance between the mobile user and transmitter is 1 km.

7706-35, Poster Session

Beamforming performance for a reconfigurable sparse array smart antenna system via multiple mobile robotic systems

G. Okamoto, C. Chen, Adaptive Communications Research, Inc. (United States); C. Kitts, Santa Clara Univ. (United States)

This paper describes and evaluates the beamforming performance for a flexible sparse array smart antenna system that can be reconfigured through the use of multiple mobile robots. Current robotic systems are limited because they cannot utilize beamforming due to their limited number of antennas and the high computational requirement of beamformers. The beamforming techniques used in this paper are unique because unlike current beamformers, the antennas in the sparse array are not connected together but instead each robot will has a single antenna. This work is made possible through breakthroughs by the authors on ultralow computational complexity beamforming and multi-mobile robot cluster control. This new beamforming paradigm provides spatial reconfigurability of the array to control its location, size, inter-antenna spacing and geometry via multi-robot collaborative communications. Simulation results evaluate the effectiveness of various beamforming techniques when 1, 2, 3, 4, and 8 robots are utilized. The simulation results are also evaluated for multiple geometric configurations for the robots, evaluating whether or not different geometric shapes may provide greater range or interference mitigation performance for different communications scenarios. Preliminary over-the-air measurement results are provided via the flexible SDR communications hardware platform integrated with the individual robotic systems.

7706-20, Session 5

Optimum detection in non-Gaussian noise by the generalized detector with Rayleigh-fading dispersive channels

V. P. Tuzlukov, Kyungpook National Univ. (Korea, Republic of)

This paper discusses the problem of detecting one out of M Gaussian correlated signals employing the generalized detector, which is constructed based on the generalized approach to signal processing in noise, in impulsive noise. The impulsive noise is modeled as a compound-Gaussian, possibly, correlated process. We first show that, for uncorrelated noise, the detection problem admits the same optimum solution, in the sense of attaining minimum error probability, for the conventional generalized detector and this solution does not depend on the noise statistics: the generalized detector amounts to an estimation block, aimed at measuring the short-time noise power spectral density, whose output is fed to a bank of estimators, each keyed to one of the M admissible waveforms and to the estimated power spectral density. We also give suggestions for realizing a suboptimum generalized receiver, with reduced complexity, which again is canonical in its structure. As for the performance analysis, we focus on binary frequency-shift keying (BFSK) signaling. We provide numerical results for two particular channel correlations and for Cauchy-distributed noise. These results indicate that, like for the general Gauss-Gauss case, the performance depends on the energy contrast, as well as on the "time-bandwidth" product of the useful signal. Moreover, noise spikiness seems to negatively affect the performance, in the sense that heavier and heavier high-amplitude tails of the noise marginal distribution give rise to higher and higher error probabilities for fixed energy contrast and time-bandwidth signal product. Comparative analysis with the conventional receivers shows that in spite of this negative affect on the performance the generalized receiver outperforms the conventional receivers in the error probability.

7706-21, Session 5

An arbitrarily accurate method of performance evaluation for asynchronous CDMA systems with zero-correlation-zone coding in Rayleigh fading

X. Chen, E. L. Walker, Southern Univ. (United States)

In this paper, we consider the problem of computing the bit error rate of CDMA systems with ZCZ (zero-correlation-zone) coding method. We have derived an exact formulation for the computation of bit error rate. Moreover, we have derived new computational approaches to achieve an arbitrarily prescribed level of accuracy for BER computation. Finally, we have generalized the formulation to address the effects of asynchronization for ZCZ coding.

7706-22, Session 5

Adaptive sphere decoding for space-time codes of wireless MIMO communications

X. Chen, E. L. Walker, Southern Univ. (United States)

In this paper, we develop an adaptive sphere decoding technique for space-time coding of wireless MIMO communications. This technique makes use of the statistics of previous decoding results to reduce the decoding complexity of subsequent decoding process. Specially, we propose a method for the determination of the initial sphere radius for the decoding process of future time-frame based on a queue of records of minimum sphere radius obtained from the decoding process of previous time-frames. An explicit formula is derived for the calculation of an appropriate queue size. Numerical simulation is performed for demonstrating the efficiency of the adaptive technique.

7706-23, Session 5

Transmit beamforming for MIMO multiuser uplink with full or partial channel state information

S. Xi, M. D. Zoltowski, Purdue Univ. (United States)

The multiple-input multiple-output (MIMO) multiuser uplink where each user adopts beamforming for transmission is considered. First, assuming that multiuser channel state information (CSI) is perfectly known to all users, we jointly optimize the transmit beamforming vectors (or beamformers) for multiple users under both the signal-to-interference-plus-noise ratio (SINR) based criterion and the capacity based criterion. Then, considering a more realistic situation where feedback is limited and thus only partial CSI at the transmitter is available, we propose several algorithms based on the Lloyd's vector quantization method to design multiuser transmit beamformer codebooks that are optimal under the same considered criteria.

One of the two major steps in the Lloyd's method is to find the optimal code for a given partition of the channel sample set. We solve this problem either via the genetic algorithm or by modifying optimization algorithms developed previously for the ideal case of perfect full CSI feedback. An issue with the codebook design is that different codebooks are needed for different values of total or individual power constraints, and this means a great deal of storage cost at both the users and the base station. We solve this issue by considering a possible range for the power constraints and augmenting the channel sample set by adding the power constraint samples. With this method, only one codebook is needed for different power constraints and its performance, as shown by simulation results, is almost the same as that using the codebook corresponding to the exact power constraints.

7706-24, Session 5

Preamble design requirements for spectrally efficient CPM waveforms

J. Pugh, P. Vigneron, C. Brown, Communications Research Ctr. Canada (Canada)

Time Division Multiple Access (TDMA) systems operating on narrowband channels typically require the insertion of a preamble into the transmit signal to allow estimation of frequency and phase offset, frame synchronization and symbol timing at the receiver. Traditionally, the preamble is comprised of at least two parts that allow these parameters to be estimated in a straightforward way: (1) a continuous-wave (CW) or repeating symbol sequence from which the frequency and phase offsets (possibly also data rate and symbol timing) may be estimated, followed by (2) a unique start-of-message (SOM) sequence for frame synchronization (and possibly symbol timing). Prior to demodulation and decoding of the message sequence, the receiver must extract coarse parameter estimates from the preamble, apply offset correction to the sampled signal and initialize the phase tracking loop.

In this work we discuss the fundamental tradeoffs and requirements in the design of a simple preamble structure consisting of a CW-section followed by a SOM sequence. The results are based on Cramer-Rao bounds for frequency, phase and timing estimation, and are also supported through simulation of efficient algorithms. The minimum CW and SOM section lengths are established based on statistical requirements for symbol timing accuracy and successful phase lock. In the interest of simplifying preamble processing in the receiver, the feasibility of a fixed rate preamble sequence for supporting multiple data rate modes is examined. Finally, within the context of spectral mask constraints, the timing error tradeoff between preamble signalling rate and pulse shape is investigated for the support of bandwidth efficient continuous phase modulation (CPM) modes.

7706-25, Session 5

A subspace-based parameter estimation algorithm for Nakagami-m fading channels

S. A. Dianat, R. M. Rao, Rochester Institute of Technology (United States)

Estimation of channel fading parameters is an important task in the design of communication links such as maximum ratio combining (MRC). The MRC weights are directly related to the fading channel coefficients. In this paper, we propose a subspace based parameter estimation algorithm for the estimation of the parameters of Nakagami-m fading channels in the presence of additive white Gaussian noise. Comparisons of our proposed approach are made with other techniques available in the literature. The performance of the algorithm with respect to the Cramer-Rao bound (CRB) is investigated. Computer simulation results for different signal to noise ratios (SNR) are presented.

7706-26, Session 6

A novel internetworking protocol of self-organization positioning wireless sensor network

X. Lai, Tsinghua Univ. (China); J. Li, N. Wu, Nanjing Univ. (China); X. Li, Nanjing Univ. (China) and New York City College of Technology (United States)

There are many key applications of the positioning service for both military use (e.g. an individual soldier located in the field troops) and civilian use (e.g. a wounded person in earthquake located for the emergency response). In the distributed background, we consider the distributed transmitters as a special wireless sensor network, and the position of each sensor can be solved rapidly. We design a new internetworking protocol for the time of arrival (TOA)-based positioning wireless sensor and the base station. The experimental result shows that this protocol can improve the precision of positioning, extend the lifetime of sensors, and also reduce the multipath effect. We study the problem of the base station movement. A robust self-organization real-time positioning network can be built with such protocol.

7706-27, Session 6

Identification and description of coverage holes in a wireless sensor network using graph theory and homology

S. Uribe, Univ. EAFIT (Colombia)

Identifying coverage holes makes an important topic for optimization of quality service for wireless sensor network hosts. This paper introduces a new way to identify and describe how is the network's structure, its number of holes and its components, assuming there's a sensor covering an area where a network communication exists. The simplicial complex method and algebraic graph theory will be applied. Betti numbers and Euler characteristics will be used for a sensor network represented by a simplicial complex, and the Tutte polynomial will be used for describing visual graphs algebraically, for a complete identification.

7706-28, Session 6

Ensuring data integrity through trust in wireless sensor networks

H. Deng, G. Jin, R. Xu, Intelligent Automation, Inc. (United States); F. Harlow, Air Force Research Lab. (United States)

Since the use of wireless sensor networks (WSNs) continues to increase for the daily operations in both commercial and defense sectors, designing an efficient and secure query processing mechanism becomes critical to assure a continued presence in various Cyber realms. While recent research efforts on database based query processing dramatically improves the efficiency of query processing, another critical component, security, is still missing. The intent of this work is to develop an efficient trusted querying mechanism to identify the trustworthiness of sensor nodes, and filter out bogus data in the querying process. Our main strategy here is to analyze various security breaches during the querying process, fully exploit the advantages of existing trust management mechanisms, and extend them into the WSNs. Our final goal is to return the highest-fidelity data response to the user while monitoring the health of the network by flagging suspected compromised nodes. It is noted that the proposed trusted querying mechanism does not eliminate the utilization of any conventional cryptographic approaches, and it works as an additional component to provide a complete solution for developing secure and trustworthy sensor networks, especially when a node is compromised.

7706-29, Session 6

Information-theoretic bounds on security overhead in mobile ad hoc networks

F. M. Ham, E. Y. Imana, W. H. Allen, R. A. Ford, Florida Institute of Technology (United States)

A Mobile Ad Hoc Network (MANET) is a self-configuring network consisting of mobile nodes which are interconnected through the wireless media without the assistance of any centralized control unit. Due to the potential sensitivity of the MANET's applications it requires the incorporation of a robust security system to protect the network from various threats it might encounter. The unpredictable dynamic topology of a MANET results in huge routing overloads which consumes

a significant percentage of the channel bandwidth. This can render bandwidth a very scarce resource in a MANET. Hence, the design of a security algorithm for a MANET should always be accompanied by a careful analysis to determine its overload on the network. This paper presents an information-theoretic analysis which is used to estimate the bandwidth-overload created by reputation-based defense systems for MANETs. A simplified MANET simulation is used to verify the use of the mathematical expressions that are derived in this research.

7706-30, Session 7

Asymptotically optimal detection/localization of LPI signals of emitters using distributed sensors

N. Vankayalapati, S. M. Kay, Univ. of Rhode Island (United States)

M intercepting sensors placed at different locations are each collecting N time-samples. The problem is to detect the presence of an unknown signal in the collected samples and to estimate the emitter location.

Current detection techniques are solely based on energy detection, ignoring the cross-sensor correlation information.

Existing TDOA/FDOA based localization techniques pair up the sensors and perform pair-wise processing which is highly inefficient.

We derived the generalized likelihood ratio test (GLRT) detector which optimally combines the energy and cross-sensor correlation information. We computed the maximum likelihood estimate (MLE) for target location which efficiently uses the TDOA/FDOA information from all the sensors simultaneously.

We first proposed the following model. The signal at each sensor is attenuated and phase shifted depending on various factors and these can be different at each sensor. The signal is also time-delayed and, in the case of moving targets, Doppler-shifted by a different value at each of the sensors. Putting these together yields a bilinear model which is a function of time-delay and Doppler-shift. When the time-delay and Doppler-shift are substituted with their corresponding functions of target location and velocity, we have a bilinear model which is a function of target location and velocity. We first compute the MLEs for the target location and velocity and use them in the computation of the GLRT test statistic. The GLRT test statistic came out to be the maximum eigen-value of the complex-ambiguity-function (CAF) matrix which is the matrix of CAFs of every sensor pair combination.

7706-31, Session 7

Cooperative data dissemination to a mission site

F. Chen, The Pennsylvania State Univ. (United States); M. P. Johnson, A. Bar-Noy, The City Univ. of New York (United States); T. F. La Porta, The Pennsylvania State Univ. (United States)

Timely dissemination of information to mobile users is vital in many applications. In a critical situation, no network infrastructure may be available for use in dissemination, over and above the group of users themselves. We consider the following specialized content distribution application: a group of users equipped with wireless devices build an ad hoc network in order cooperatively to retrieve information from certain regions (the mission sites). Each user requires access to some set of information items originating from sources lying throughout a region. Each user desires low-latency access to its desired data items, upon request (i.e., when pulled). In order to minimize average response time, we allow users to pull data either directly from sources or, when possible, from other nearby users who have already pulled, and continue to carry, the desired data items. That is, we allow for data to be pushed to one user and then pulled by one or more second users. The total latency experienced by a user vis-à-vis a certain data item is then in general a combination of the push delay and the pull delay. We assume each delay time is a function of the hop distance between the pair of points in

question.

Our goal in this paper is to assign data onto mobile users, in order to minimize the average total latency experienced by all the users. We formulate this problem as an integer program and prove it to be NP-hard even to approximate. We then develop distributed algorithms which are efficient and easily deployable in wireless ad hoc networks. Through simulations, we show that our algorithms typically achieve near-optimal performance.

7706-32, Session 7

CMOS compatible microscintillators for wireless multispecies radiation detection and tracking

R. Waguespack, Louisiana Tech Univ. (United States)

This paper reports on an integrated system of wirelessly linked radiation detectors that are sensitive to alpha, beta, gamma, and neutron radiation. The detectors use glass and quartz doped with 10B nanoparticles to detect impinging radiation producing varying optical pulses which exit the material. The varying optical pulses are differentiated by on-chip pulse height spectroscopy. Signal discrimination is done with on-chip CMOS circuitry and a photodiode using 0.35 μm process. On-chip CMOS interfacing is key to the production of small integrated radiation detection packages that are cheaper, more reliable, and easier to produce than assembled devices that use commercial off-the-shelf parts. CMOS packages are designed for low power consumption with maximum battery life; this lends itself to creating small, hard to detect radiation sensor packages that are easy to integrate with wireless sensor nodes. The network uses a mesh configuration and transmits real time radiation information from each node to a local hub. As a radiation source enters the coverage area the data from sensors in the immediate area is transmitted and compared to find the location of the source. Pinpointing the source is achieved by comparing data receive from each node. Radiation testing was done using 241Am, 90Sr, and 60Co sources for alpha, beta, and gamma particles. Initial results show that quartz and glass scintillator doped with boron is able to detect each forms of radiation. The quartz scintillator is also able to detect neutron radiation particles, which being neutral, are undetected with traditional solid state radiation detectors.

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7707-01, Session 1

UAS control segment (UCS)

J. Springer, U.S. Army (United States)

Entered by T P-R, will update with info from chair.

7707-04, Session 1

Fuel cell systems for long duration electric UAVs and UGVs

P. Osenar, J. Baldic, N. Lauder, P. Launie, Protonex Technology Corp. (United States)

Protonex is a leading provider of advanced fuel cell power systems for portable, remote and mobile applications. Protonex has been working on optimizing PEM fuel cell system power density for applications such as small UAVs and UGVs. Both of these applications require power systems with both high power density and high energy density. Within the 100-1500 watt power requirements, we have shown that fuel cell systems can outperform battery systems by a factor of 2-6x. Integration of fuel cell power systems into these platforms can provide significant additional mission capabilities for military and civilian applications. The performance benefit over incumbent power technologies is leading to significant near term product opportunities.

The next generation of UAS missions will require the stealth of electric propulsion in addition to long mission times (up to a day or more). The current batteries available will have a difficult time meeting the energy density necessary for these long durations with the current power needs. While there are many avenues for improved efficiencies and lower power consumption on the existing platforms, it is also valid that systems developers would like to add greater power capabilities.

Protonex has developed advanced power sources based on fuel cell-battery hybrid systems that outperform existing battery technology by several factors. Our advanced power systems have been demonstrated in a variety of existing and experimental platforms including AeroVironment's Puma UAV, Foster-Miller's Talon UGV, NRL's Ion Tiger, and XFC UAVs. Currently, we are developing harden systems for fielding in at least one hand launchable UAV for field deployment in 2010.

7707-05, Session 1

Whole-body task energy metrics for robots performing useful work in unstructured environments

D. A. Theobald, A. Hofmann, Vecna Technologies, Inc. (United States)

When considering energy requirements and optimization for robots, it is important to consider mission requirements, and the type of robot performing the mission. For example, the small robots used in today's reconnaissance and EOD applications have weak manipulators, and do not perform significant physical work on their surrounding environment. In this paper, we focus on robots that will be required to do much more physically demanding tasks, such as manipulating large heavy objects in unstructured environments, and carrying such objects over challenging terrain. Energy considerations for such systems must include models of physical work performed for basic manipulation, pose transition, and locomotion maneuvers.

Given the scarcity of robots that can perform useful work in unstructured environments, it is useful to begin the investigation of energy optimization for such robots by considering typical tasks they might perform. This paper makes three contributions in this direction. First, we develop a set of standard tasks that would be useful in unstructured environments. The tasks are expressed in terms of the objects being manipulated, and the work being done, so they are independent of robot morphology. Second, we develop energy metrics and analytical results for theoretical energy requirements for these tasks. These requirements assume no losses due to friction, so they give a best-case estimate of what is achievable. Such metrics are useful in subsequent evaluation of real systems that are not as efficient. Third, we perform preliminary comparisons between different actuation technologies in performing these tasks. These actuation technologies will include electro-mechanical and hydraulic systems. We compare these technologies in terms of power density, and evaluate expected energy efficiency when performing the metric tasks.

7707-15, Session 1

All weather collision avoidance for unmanned aircraft systems

M. R. Contarino, Scire Consultants LLC (United States)

For decades, military and other national security agencies have been denied unfettered access to the National Air Space (NAS) because they lack a highly reliable and effective collision avoidance capability. The controlling agency, the Federal Aviation Administration, justifiably demands "no harm" to the safety of the NAS.

To overcome the constraints imposed on Unmanned Aircraft Systems (UAS) use of the NAS, a new, complex, conformable collision avoidance system has been developed - one that will be effective in all flyable weather conditions, overcoming the shortfalls of other sensing systems, including radar, lidar, acoustic, EO/IR, etc., while meeting form factor and cost criteria suitable for Tier II UAS operations. The system also targets Tier I as an ultimate goal, understanding the operational limitations of the smallest UASs may require modification of the design that is suitable for Tier II and higher.

The All Weather Sense and Avoid System (AWSAS), takes into account the FAA's plan to incorporate ADS-B (out) for all aircraft by 2020; and it is intended to make collision avoidance capability available for UAS entry into the NAS as early as 2013. When approved, UASs can fly mission or training flights without constrained access to the NAS presently in place.

When implemented this system will achieve collision avoidance capability for UASs deployed for national security purposes and will allow expansion of UAS usage for commercial or other civil purposes.

7707-06, Session 2

Software defined radio-based multi-carrier multi-function waveform

V. D. Chakravarthy, Air Force Research Lab. (United States); Z. Wu, Wright State Univ. (United States)

No abstract available

7707-07, Session 2

Efficacy of compressive sensing for dynamic spectrum access

O. Odejide, A. Annamalai, Jr., C. M. Akujuobi, Prairie View A&M Univ. (United States)

Compressive sensing (CS) relies on the fact that CS sampled signals are much closer to their information rate rather than the signal bandwidth. This attribute helps to provide the much needed benefits of reduced storage or transmission bandwidth for the next-generation broadband wireless communications and to overcome the hardware limitations for wideband spectrum sensing in dynamic spectrum access. In order to opportunistically reuse holes in the spectrum, it is essential to have a spectral detection and estimation technique that is capable of sensing and identifying available frequency bands. Conventional methods of detection are saddled with the high sampling rate requirement of Nyquist rate, however timing requirements limits the number of samples that can be taken from the signals. In a situation whereby the signal spectrum in open-access networks is sparse in nature, this work develops a detection mechanism for identifying spectrum holes using compressive sensing based algorithm technique. Different compressive sensing reconstruction algorithms are investigated and FFT spectrogram with an edge detection algorithm is used to identify the holes in the spectrum. A quick wideband spectrum sensing can be achieved using the compressive sensing technique and a more refined sensing can be used by any of the other available methods such as energy detection. The proposed model is evaluated in different fading propagation environments, taking into account of both additive and multiplicative noise.

7707-08, Session 2

Wideband signal detection using a Nyquist folding analog-to-information receiver in multipath fading environments

O. Odejide, A. Annamalai, Jr., C. M. Akujuobi, Prairie View A&M Univ. (United States)

The need to efficiently and effectively monitor the frequency spectrum for identification of unoccupied bands is essential in communication systems such as Cognitive Radio (CR), battlefield communications, etc. The Nyquist Folding Analog-to-Information Receiver (NYFR) which is based on the theory of Compressed Sensing has been proposed recently to address this problem in a sparse environment. Although, typical CS techniques, involve random projections followed by a computationally intensive signal reconstruction process, the methods used in NYFR does not requires the laborious l1 minimization algorithm. The NYFR performs analog compression via a non-uniform sampling process that induces a chirp-like modulation on each received signal. Signal parameters can simply be determined by using time-frequency analysis techniques without full signal reconstruction. This paper revisits the detection problem of using NYFR for information recovery for appropriate frequency detection when the original signal in the presence of both the additive white Gaussian noise and Rice multipath fading. An automatic detection algorithm was also developed to determine the detected frequency parameters without looking at the FFT spectrogram plot.

7707-09, Session 2

Congestion game model for efficient utilization of spectrum

Y. B. Reddy, Grambling State Univ. (United States)

Dynamic spectrum access is a way of gaining access to individual frequencies on a temporary basis. This makes use of frequency assigned to a specific user (primary user) by using specific devices and/or spectrum management techniques. The spectrum management techniques can be done by allocating the spectrum (a) through auction (market based), (b) using management techniques (c) spectrum sharing (detects and utilizes the unutilized part of the spectrum) (d) command and control, and (e) through opportunistic spectrum access. In opportunistic spectrum access, the secondary or unlicensed user transfers the data with high speed and at short distances with tolerable interference (without disturbing) to the primary signal. Efficient spectrum allocation techniques were discussed using stochastic models, economic models,

genetic algorithms, and optimization techniques. In opportunistic access, the secondary or unlicensed user transfers the data with high speed and tolerable interference (without disturbing) to the primary signal. The current models need to be tuned for better performance with optimum utilization of the power.

In this paper, we proposed a model that provides access with tolerable interference from secondary users to the primary users while maximizing the spectrum utilization. Furthermore, we designed congestion game model for efficient utilization of spectrum by the secondary user with minimum interference to the primary user. The results show that the congestion game model produces better results.

7707-10, Session 2

A fuzzy logic approach to cross-layer route optimization in multi-hop CRNs

R. Murawski, E. Ekici, The Ohio State Univ. (United States); R. W. Thomas, Air Force Institute of Technology (United States)

Methods for selecting and optimizing end-to-end network routes have been heavily researched. Typical route optimization schemes focus on maximizing network utility based on a single metric. In this research, we propose a cross-layer route optimization algorithm for route optimization in multi-hop cognitive radio networks. The first step in meeting this challenge was to understand what cross-layer information could be collected and how to organize such information. In this paper, we define a hierarchical organization for cross-layer statistics which defines what information can be gathered and to how this information can be used to define the end-to-end network utility. Next, we developed a means of objectively comparing alternate end-to-end network routes based on gathered cross-layer statistics. A multi-variant utility function, based on the concepts of Fuzzy Logic modeling was developed that defines the relative quality of a given route based on multiple cross-layer statistics. We show that this utility function can be generated quickly and that it can be tuned to the specific application layer requirements of a given network service. Finally, we incorporate this multi-variant utility function with well known route optimization algorithms to meet our goal of maximizing the route utility for the network as a whole.

Using these route optimization techniques, we will show that by maximizing the network utility based on the gathered cross-layer information, the quality of the network for all users can be improved.

In future work, this route optimization technique can be extended to communication channel selection for a multi-channel cognitive radio network.

7707-11, Session 2

Algorithms for rate maximization in cognitive radio networks

R. Kannan, J. Zhang, S. Wei, Louisiana State Univ. (United States)

In a typically cognitive radio network, observations of the operating environment are coupled with the radio's available hardware and software capabilities to modify the radio's behavior and optimize its performance. The underlying system model can be described as follows: Assume a spectrum of K channels licensed to the primary users. A cognitive transmitter-receiver pair must decide on a specific channel out of the subset of K total channels that are unoccupied. Typically, a secondary receiver senses the available spectrum of K channels by sequentially sensing channel j: j = 1, 2, \ldots, i-1, i$ for a given sensing period $delta_j$ until it arrives at the first channel (channel i) that it senses as unoccupied. The receiver provides feedback to the transmitter, which must then decide to transmit or not during the current transmission period (time slot). In this paper, we model primary channel occupancy patterns and the associated secondary decision problem as a Stochastic Decision Process and develop online algorithms for their

solution. For cases when the primary traffic and channel occupancy patterns are completely unknown, we present optimal online algorithms that guarantee secondary performance (in terms of channel rates) with a bounded competitive ratio regardless of the underlying behavior of the primary. The competitive ratio of our online algorithm is bounded against the best-possible offline algorithm (the offline optimal with full i.e apriori knowledge of the primary's channel behavior). We also develop competitive probabilistic online algorithms when the primary channel behavior is initially unknown but learned over time.

7707-12, Session 2

Multi-UAV tomography-based geolocation of RF emitters

D. J. Walter, J. T. Klein, J. R. Kaupert, Rose-Hulman Institute of Technology (United States); C. Bullmaster, V. D. Chakravarthy, Air Force Research Lab. (United States)

Various methods for discovering the location of radio frequency (RF) emitters using unmanned aerial vehicles (UAVs) have been the focus of research over the past several years. Our work is aimed at determining the effectiveness of a tomographic method to locate RF emissions using low-accuracy direction finding (DF) technology. Small, commercial-off-the-shelf (COTS) antenna systems can provide a rough estimate of an emitter's location within a 90 degree or 45 degree sector. Using these DF systems, a team of inexpensive UAVs can be deployed to collect low-accuracy data from multiple positions. A ground station would combine the information. In contrast to typical angle-of-arrival (AOA) methods, this unique technique does not require precise antenna arrays, complex hardware, or significant processing time to locate RF emissions.

A MATLAB-based simulation test-bed has been developed to model the RF signals collected, given a scenario of user defined UAV flight paths. Tomographic reconstruction techniques are used to synthesize RF signals collected from these coarse DF sensors and pinpoint a highly accurate position of the unknown emitter. Scenarios are simulated by varying parameters of interest. System tradeoffs, such as number of UAVs, coarseness of the antenna direction finding capability, and flight paths traveled are used to optimize the system. Measures of the geolocation accuracy and how quickly it is achieved are used as a benchmark for comparison between simulated scenarios. The effectiveness of this method will be evaluated against existing methods. Advanced systems could use geolocation feedback information to optimize flight paths in real-time.

7707-13, Session 2

Dynamic spectrum access in wireless ad hoc networks: overview and open issues

Z. Zhang, T. Soni, Argon ST, Inc. (United States)

The current DOD communication system is impacted by DOD spectrum auctions, political and regulatory decisions as well as tactical demands that reduce spectrum access. The DOD community needs more flexibility in the way frequencies are assigned and managed to keep pace with the increased complexities of today's systems. Current communications systems rely on fixed frequency assignments within a time division multiple access (TDMA) structure for interference free channel access. The frequency allocations are assigned by a site frequency manager based on requirements for specific applications. Frequency planning and assignment are done manually and result in inefficient use of spectrum. When observed in a frequency-time plane, the actual instantaneous use of spectrum is minimal. This implies that the issue is not the lack of spectrum itself but the ability to manage efficient real-time spectrum access on a non-interfering basis. The need for dynamic spectrum access is paramount given the loss of available spectrum due to Government auction combined with the increased demand placed by modern wideband communications systems. A gap exists between the need for spectrum and the ability to access it dynamically in the frequency-time plane.

To fill in this gap, Dynamic Spectrum Access (DSA) and cognitive radios/networks have been proposed in wireless ad hoc networks. DSA radio software is a real-time frequency agile management and access technique that allows networked radios to dynamically access available RF spectrum. Rather than have RF spectrum statically assigned to the tactical system under test and the test system DSA allows the system to dynamically allocate spectrum on a non-interfering basis. The general DSA approach employs signal-detection-based interference avoidance algorithms, a set of policy-based components, tightly integrated with the accredited kernel on the radio that avoid potentially harmful interference when systems have access to the same spectrum. This capability has the added benefit of protecting any user from interference caused by a malfunctioning device. The policy conformance and enforcement components ensure that the networked radios will not violate policies, which define regulatory compliance and the tactical system's goals and requirements.

Deploying DSA in existing networks offers the following benefits to DOD community:

- It brings unprecedented levels of frequency agility to enable more efficient use of the spectrum for DOD applications

- It manages spectrum resources in real-time enabling maximum time-frequency agility

- It removes the manual, inefficient frequency assignment duration initialization

- It increases the system reliability by dynamically assigning frequency based on the traffic demand and channel conditions, either replacing degraded channels or harvesting other underutilized channels.

- It reduces the response latency

However, these benefits do not come free. Extra devices such as detectors are needed and extra overhead are required to implement DSA. These extra overhead include time allocated for detection and control message exchanges to coordinate the channel switching. There is a trade-off in terms of the cost of extra devices and gain these extra devices bring and a trade-off in terms of extra overhead versus the network performance improvement. Obviously, the more time allocated for detection, the better the detector can detect the available spectrum; the more time allocated for control information exchanges, the more efficient the spectrum allocation schemes are. On the other hand, the more time allocated for detection and control information exchanges, the more bandwidth are consumed which in turn consumes more network resource and decreases the network performance. These trade-offs must be studied carefully so the benefits of the DSA can be fully utilized.

In this paper, we will study these trade-offs. We will present a model that includes the cost of spectrum sensing/detection and extra overhead. We will use this model to investigate the relationship between overhead and efficiency. We describe our work on dynamic spectrum allocation, considering both centralized and distributed approaches to solve the dynamic allocation problem. This will lead us to study the price of anarchy for DSA networks. The price of anarchy is defined as the price that a decentralized system should pay for not being coordinated.

We will also discuss some of open issues:

- Need to study the characteristic of the available spectrum so that the appropriate spectrum allocation schemes can be developed. The parameters of interest are mean and variance or probability distribution of the time period during which a certain level of bandwidth is availability.

- Need to study the hardware limitation: the bulk of existing wireless devices does not support DSA features and functions and needs to be replaced by a new set of DSA-enabled devices.

- Scalability: even though there are many benefits applying DSA to existing networks, how to deploying the DSA technology to a large network is still an open issue given the constraints of the detectors and spectrum allocation coordination.

- Security: Current systems still lack strong security and authentication measures.

If more spectrums are open for others to access, it is even more susceptible to security failures.

7707-14, Session 2

Quality of service for tactical mobile wireless networks

R. Ordower, SAIC (United States)

Applications resident on tactical networks are levying increasingly large offerred load demands, exceeding feasible capacity. In parallel, radio waveforms are being designed to operate at higher frequencies to overcome capacity limitation, resultantly having greater outages/corruption due to terrain and vegetation. Ultimately, the wireless network will always be a bottleneck in transmitting "all information" at all times. This does not need to be considered a failure of the network, if managed correctly. "All information" is not necessarily critical to the soldier. Rather, the soldier is concerned with ensuring priority information is received at all times within delay tolerances. This goal can be accomplished through a combination of techniques to reduce congestion and mitigate corruption.

Over the last 5 years, SAIC has worked with Natick Soldier Center (NSRDEC) to provide reliable communication with guaranteed service quality for the dismounted soldier. The effort utilizes a series of tools to mark, shape, condense, fragment and persist information. The critical aspect of the congestion control solution is to remove network collisions. This is accomplished by adaptively throttling lower priority information at the sending node before it gets pushed to the wireless realm. Of note is that the solution adapts through passive processes without control messages. The solution also implements compression of messages and images, along with fragmentation techniques to alleviate congestion. Information corruption is purely a radio phenomenon and can not be overcome at through cognitive solutions. However, the solution mitigates corruption through information persistence and reliable retransmission. The implemented solution, unlike Transport Control Protocol, is optimized for wireless networks and demonstrates reduction of added signaling traffic. Combined congestion and corruption techniques have been demonstrated at the C4ISR OTM event at Ft. Dix, showing soldiers can get the right information at the right time during high offered loads or network outages.

7707-15, Session 2

Distributed game-theoretic topology control in cognitive networks

M. A. Fecko, E. van den Berg, C. Lacatus, S. Samtani, Telcordia Technologies, Inc. (United States)

Existing distributed approaches to topology control are poor at exploiting the large configuration space of cognitive radios and use a lot of inter-node synchronization to aim at optimality. We created a framework to design and study distributed topology control algorithms that combine network-formation games with machine learning. In our approach carefully designed incentive mechanisms drive distributed autonomous agents towards a pre-determined system-wide optimum. The algorithms rely on game players to pursue selfish actions through low-complexity greedy algorithms with low or no signaling overhead.

Convergence and stability are ensured through proper mechanism design that eliminates infinite adaptation process. The framework includes simple game-theoretic extensions to influence behavior such as fragment merging and preferring links to weakly connected neighbors. Learning allows adaptations that prevent node starvation, reduce link flapping, and minimize routing disruptions by incorporating network layer feedback in cost/utility tradeoffs. The algorithms are implemented in Telcordia Wireless IP Scalable Network Emulator. Using greedy utility maximization as a benchmark, we show improvements of 13-40% for the metrics such as the numbers of disconnected fragments and weakly connected nodes, topology stability, and disruption to user flows. The proposed framework is particularly suitable to cognitive radio networks because it can be extended to handle heterogeneous users with different utility functions and conflicting objectives. Desired outcome is then achieved by application of standard cooperation techniques such as utility transfer

(payments) and insurance schemes. Additional cross-layer optimizations are possible by playing games at multiple layers in a highly scalable manner.

7707-16, Session 2

A distributed and adaptive fault management and self-healing scheme for tactical networks

H. Deng, Intelligent Automation, Inc. (United States)

With the increasing demand for wireless data sharing and computing in tactical networks, demands for improved network fault management are also increasing. Significant research has been conducted in the area, however, most of them either focuses on fault management in traditional infrastructure networks, or addresses more on fault detection and localization, and ignores the critical needed fault restoration, or self-healing capability. In this paper we propose a distributed and adaptive network fault management and self-healing scheme to support automatic decision-making in tactical networks. The proposed scheme exploits existing technologies and presents an efficient fault management and self-healing solution. It provides the following advantages: 1) a distributed, hierarchical management architecture that avoids many drawbacks suffered by a centralized and flat network management architecture, and provides low overhead, fast response, high reliability, and high scalability; 2) a cross-layer self-healing approach that provides a more reliable self-healing solution by considering multiple feasible solutions at each layer, their interdependencies, and the potential impact on the real network when they are applied; and 3) a robust and self-organized design that is adaptive to and tolerant of the topology changes, node movements, and network configuration/reconfiguration of tactical networks.

7707-17, Session 3

Building net-centric data strategies in support of a transformational MIW capability

M. Cramer, U.S. Navy (United States); J. Stack, Office of Naval Research (United States)

No abstract available

7707-18, Session 3

Locative viewing: visualizing geo-referenced objects in space

M. J. Carlotto, M. Nebrich, P. Hylton, General Dynamics Advanced Information Systems (United States)

Locative Viewing is a method for visualizing geographically-referenced 3-D objects in the local coordinate system of a geographically-referenced observer. Also known as Augmented Reality, a computer-graphics rendering of nearby geo-objects is superimposed over the visual surroundings of the observer as seen by a camera. The rendering changes as the observer moves. Locative viewing can be accomplished with a mobile device that is able to determine its geographic location, and orientation, contains a camera and image display, and can project and overlay objects within the field of view of the camera with the camera image. Locative viewing eliminates the difficulty in visually correlating a map-view with one's surroundings and significantly reduces mobile communications bandwidth (most of which is used in sending a map or image background over which geo-referenced objects are often displayed). A preliminary implementation of a locative viewer using Apple's iPhone is described and results presented.

7707-19, Session 3

System approach to distributed sensor management

G. Mayott, U.S. Army Night Vision & Electronic Sensors Directorate (United States); G. J. Miller, J. Harrell, Oakwood Controls, Inc. (United States); J. J. Hepp, Invoke Corp. (United States)

NVESD is developing a Distributed Sensor Management System (DSMS) that provides net-centric sensor management at the application layer. The core principles of the design support distributed and dynamic discovery of sensing devices and processes through a multi-layered implementation. This results in a sensor management layer that acts as a System with defined interfaces for which the characteristics, parameters and behaviors can be described. The DSMS and its application to a tactical sensor network will be described in this paper.

The DSMS protocol defines required behaviors, capabilities and message structures. The protocol definition addresses the requirements for a sensing device to dynamically join and leave a sensor network, dynamically describe device control and data generation capabilities, and allow dynamic addressing of publish and subscribe functionality by the end user application. The message structure definition provides a multi-tiered description beginning with a rigid definition of Standard functions and parameters associated with a particular sensing modality. This standard definition provides an abstraction that provides a solution for minimizing and normalizing the disparate control definitions across the many sensing device interface descriptions used today. A second tier definition allows the developer to extend the functional capabilities using natively described data objects. Lastly a general data payload definition is provided to accommodate rapid prototyping. The dynamic qualities of the protocol enable a User GUI application the flexibility of mapping widget-level controls to each device based on reported capabilities at run-time. As a system DSMS is designed to accommodate scalability and flexibility within a defined architecture.

7707-20, Session 3

Analytical approach for assured information system performance analysis

S. V. Belur, The Van Dyke Technology Group, Inc. (United States)

A multi-class open network queuing theory approach is formulated to describe the performance of an assured information system. The information system is characterized by its nodes and transactions between those nodes. The nodes and transactions of the system are generated based on the use cases of the information system. The performance of the system is characterized by the response times for certain specified use cases of the system. The nodes and transactions vary depending on various factors. Some of the contributing factors are the type of certificate validation used to identify and validate the users, extent of user information caching that is applied , and the service distributions or centralization. Thus the performance of the system becomes a function of these variables. The model developed for the performance analysis is demonstrated with some examples.

7707-21, Session 3

Resource brokering service: timely and efficient information resource allocation

D. J. Van Hook, M. Ljungberg, M. Ford, Lincoln Lab. (United States)

We address supporting unanticipated users and uses of limited information resources (sensors, databases, weapons - any resource intrinsically tied to digital information) in a timely and efficient fashion. Platform-centric systems often preclude users and uses not identified

when the system was developed and deployed. Net-centric approaches, however, can address these problems by allowing services and information to be discovered and accessed at run-time. We have developed a Resource Brokering Service (RBS) that uses net-centric principles to enable multi-domain information and resource sharing and support unanticipated users and uses. The RBS uses federated brokering agents and a modular software component framework for dynamically composing and tasking heterogeneous resources including sensors, processors, databases, networks, and even analysts into resilient, mission-oriented workflows. The RBS is applicable to multiple sense-decide-act military domains including missile defense, space situation awareness, ISR, border protection, and cyber defense. In this paper we describe the concept and architecture of the Resource Brokering Service, modeling and simulation evaluation, results from recent field tests, and lay out a path forward.

7707-22, Session 3

Net-centric interoperability

M. T. Sevening, The Boeing Co. (United States)

This presentation is a net-centric approach to addressing system and interoperability design, engineering, testing, and fielding concerns. First, it classifies interoperability into three distinct areas with specific attributes and disscuses the attributes of each interoperability classification. Second, it discusses the three classifications in relation to the seven open system interconnections layers. Last, it details analysis possibilities using the interoperability matrix presented.

This presentation classifies interoperability into three distinct areas: integrated interoperability, system-to-system interoperability, and collaborative interoperability. The presenters define the three areas as follows. Integrated interoperability is a function of messages sent through the network to a destination. System-to-system interoperability is a function of information and other participating elements use of perishable data. Collaborative interoperability is a function of awareness and coordinated actions by each participating elements and of the entire system-of-systems.

Ultimately, the presenters propose their method for use across designing, engineering, testing, fielding, and analysis phases of network centric operations to improve the effectiveness of interoperability.

7707-23, Session 3

Security core to the edge: securing critical information through enhanced cross domain systems (CDS) to the tactical edge

B. S. Farroha, Northrop Grumman Information Systems (United States); M. M. Whitfield, D. L. Farroha, U.S. Dept. of Defense (United States)

The traditional philosophy of minimal data sharing outside a security domain has been replaced by an era of encouraging secure information sharing among services, agencies, coalition partners and state/local organizations. This new viewpoint also includes providing the appropriate data to the tactical edge through means of enhanced CD methods and secure communications. This analysis presents the tactical requirements and technology roadmap to deliver the required data to the warfighter. We provide an analysis of various types and levels of protection, data integrity and alternative architecture options to support the stated Tactical CD requirements with their built-in variations. These new requirements include automated data discovery and dealing with compromised assets and codes. Additionally, the definition of the enterprise and its boundaries and where the tactical operations rules begin have been under discussion with a multitude of stakeholders. We are focusing on the tactical environment because the need is so great and it resides in a limited communications setting with variable link capacities, QoS, data bursts, error rates and multiple connectivity/handoff issues. We investigate the threat levels within the tactical environments and the effects on the overall enterprise security and integrity. The goal of a

net-centric battlefield dictates distributed architectures that are secure and connected in a manner that complements the heterogeneous components system. The overall approach will eliminate the stovepipe architectures that restrict data sharing due to the Point-to-Point approach that is prevalent in the tactical community and opens the doors to share information across traditional and non-traditional domain boundaries.

7707-24, Session 3

Metrics for measuring net-centric data strategy implementation

J. B. Kroculick, Winifred Associates (United States)

A data strategy outlines an organization's vision and objectives for improved collection and use of data. We propose generic metrics and quantifiable measures for each of the DoD Net-Centric Data Strategy (NCDS) data goals. Data strategy metrics can be adapted to the business processes of an enterprise and the needs of stakeholders in leveraging the organization's data assets to provide for more effective decision making. Generic metrics are applied to a specific application where logistics supply and transportation data is integrated across multiple functional groups. A dashboard presents a multidimensional view of the current progress to a state where logistics data shared in a timely and seamless manner among users, applications, and systems.

At the strategic level, there are multiple stakeholders and organizations that influence or control data. Consequently, a strategic approach needs to balance competing priorities among constituencies to create consensus and creating situations in which all participants have a stake in its success.

Data goals in NCDS include making data visible, accessible, understandable, trusted, institutionalized, interoperable and responsive to user needs. For each of the NCDS Data Goals, we suggest some generic metrics that can be applied to a DoD Component. NCDS Data Goals are aspects of data quality that need to be balanced in a strategic approach to using data to meet an organization's needs. Achieving data goals tied to an organizations critical success factors is a people-oriented process and involves the organization's stakeholders. The output of data management processes should be data products meeting unique needs of the organization.

Data Strategy Metrics for each of the data goals are as follows:

- Percentage of Data Assets Posted to Authoritative Data Source (Measures Data Visibility)

- Percentage of Data Assets that have Metadata (Measures Data Understandability)

- Percentage of Data Assets that have Metadata posted to Metadata Registry (Measures Data Accessibility)

- Percentage of Data Sources that are identified by an Agency as authoritative out of a total set of identified data assets (Measures Trusted Data)

- Percentage of Compliant Data Assets to a Data Standard (Measures Data Interoperability)

- Assessments and Maturity Levels on a Data Management Maturity Model (Measures Data Institutionalization)

- Net-Promoter Score (Measures Responsiveness to Stakeholder Needs)

- Percentage of Data Sources that have Web Service endpoints (SOA enabled)

There is no one set of metrics that meets every organization's need. However, by defining metrics at the strategic level they can be tailored to the tactical and operational levels and specific business applications including the logistics supply and transportation domains.

7707-25, Session 3

Countering asymmetric situations with adaptable system organizations

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

A novel ideology and technology will be described capable of countering irregular threats not so by power of numbers or weapons but rather flexible, asymmetric themselves, system organizations effectively adapting to changing goals and environments. They introduce an integral "overoperability" layer in contrast, also supplement, to traditional interoperability organizations. The layer is based on implanting into system points of a universal control module, communicating with other such modules, which collectively interpret compact high-level mission scenarios created on the fly in a special Distributed Scenario Language. The scenarios, starting from any component and covering the system at runtime, automatically establish the needed operational infrastructures orienting and controlling both local and global behavior. This allows us to shift most of traditional routines of system organization and management to automated up to fully automatic levels, concentrating on global goals and efficiency instead. The approach offers a unified framework for organization of advanced human-robotic crisis reaction forces with their gradual transition to fully unmanned distributed systems exhibiting global awareness and will, also capable of making autonomous decisions in critical situations. The technology details will be revealed along with its potential applications in robotized distributed systems of different natures. Simulated scenarios will include discovering and fighting distributed insurgency networks, also piracy swarms, the latter by open groups of unmanned vehicles combining loose swarming and global goal orientation and control, with flexible watershed between the two. www.amazon.com, sapaty in books; "Gestalt-based integrity of distributed networked systems", paper 7480-26, SPIE Europe Security + Defence, Berlin, 2009.

7707-26, Session 3

Enterprise systems security management: a framework for breakthrough protection

B. S. Farroha, Northrop Grumman Information Systems (United States); D. L. Farroha, U.S. Dept. of Defense (United States)

Securing the DoD information network is a tremendous task due to its geographic size, number of users, access locations and the amount of intrusion attempts on the network. This task includes securing all data and ensuring that the data is reliable and available to legitimate users. Methods of cryptobinding the data with metadata and sources in addition to tracking the users that have accessed compromised data are basic requirements for secure information sharing in a net-centric environment. This new SoS needs to have automatic data discovery and data stewards granting access to CD data repositories or live streaming data. Multiple architecture models are investigated to determine best-of-breed approach including SOA and Private/Public Clouds. To enable a next-generation ESM construct we need to develop the baseline technologies that support Credential and Identity Management to ensure the proper Privileges are granted. Data access is granted based on identifying the data including Attributes and Metadata and then it is distributed to authorized users based on an updated Digital Policy. The current ESM approach assumes a method of access control like RBAC, ABAC, and ZBAC, etc. Cryptographic Key Management plays an important role in protecting data at-halt and data at-the-move and therefore is required in any architecture. Secure access control would not be possible unless we know with certainty the identity, role, and other key attributes of any user who logs in, and to maintain records of this information. The proposed Privilege management system automatically grants/terminates access when policy, role, or identity changes.

Conference 7707:

7707-27, Session 4

Distributed spatiotemporal detection for chemical and biological threats using human immune mechanisms

Y. R. Bodas, S. Agarwal, S. S. Vulli, D. Singiresu, Missouri Univ. of Science and Technology (United States)

Ubiquitous detection of chemical and biological (CB) event, incident or accident in an urban environment using widely distributed, low-cost, broad-spectrum CB sensors carried by public or on vehicles is extremely desirable and pertinent for homeland security. These distributed sensors should interoperate autonomously and adaptively to meet stringent operational and detection performance requirements.

This paper explores the use of scalable detection methodology, inspired by the human immune mechanisms to meet this challenge. We propose an adaptive spatiotemporal control mechanism to organize the detection behavior of spatially dispersed sensors using peer-to-peer communication so that a shorter response time, higher probability of detection and lower false alarm rate are achieved at the system level even though individual sensors have only modest performance capabilities. The detection mechanism is developed to minimize the power consumption and required density of the sensors while achieving the desired performance requirements. Different tradeoffs between deployment strategies for the sensors and system level performance requirements are discussed. The effectiveness of the algorithm is demonstrated by carrying out extensive scaled simulations using agent-based models. Based on these simulation studies, some recommendation on the individual sensor performance requirements and achievable system level objectives are presented.

7707-28, Session 4

Co-evaluation computation-based distributed intrusion detection system

J. Su, Harbin Univ. of Science and Technology (China)

To improve detecting rates and reduce false detection of distributed network intrusion detection system, co-evaluation computation-based distributed intrusion detection system is proposed. Multi-agents evaluation computation is used to enhance self-learning ability and self-adaptation ability of network intrusion detection. Co-evaluation technology is used to speed co-evaluating of multi-agents in network intrusion detection system and then improve evaluating ability of distributed system. Experiments verify the validity of the method.

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7708-02, Session 1

Multispectral palm image fusion for biometric authentication using ant colony optimization

D. R. Kisku, BCREC (India); P. Gupta, Indian Institute of Technology Kanpur (India); J. K. Sing, Jadavpur Univ. (India)

Automatic authentication of users by their biometric characteristics is playing role in security. Biometric recognize the identity of a person with certain physiological / behavioral characteristics, such as fingerprints, face, iris, speech, hand geometry, etc. Recent advancement of brand new biometric systems, a new biometric authentication system, palmprint recognition, has been proposed and investigated [1-5]. The palmprint recognition system has many advantages over other biometric systems in respect of reliability, low cost and user friendly. Similar to fingerprint and iris, palmprint is one of the most reliable means in personal identification because of its stability and uniqueness. Different to fingerprint and iris, palmprint-based identifier is more user-friendly and acceptable. This paper presents a novel palmprint verification method in which Multispectral palm images are fused at low level by wavelet transform and fused palm is then represented by Gabor wavelet transform to capture the palm characteristics in terms of neighborhood pixel intensity changes. Gabor palm responses contain high dimensionality features and due to this high dimensionality ant colony optimization (ACO) is applied to select optimal set of distinct features. Finally, support vector machines are used to train the reduced feature sets of different individuals and verify the identity. In this classification work, binary classification work employed. Proposed palmprint system is evaluated with CASIA palmprint database and the results are also compared with other existing method to measure the effectiveness and robustness of the system.

7708-03, Session 1

Experimental study on GMM-based speaker recognition

W. Ye, D. O. Wu, Univ. of Florida (United States)

It has been shown that the Gaussian Mixture Models (GMM) is an effective statistic model for speaker recognition task. We can find GMM in most state of the art speaker recognition systems. The GMM is used to represent the "voice print" of a speaker through modeling the spectral characteristic of speech signals from that speaker. Each of the Gaussian components is used to catch up with some speaker-dependent spectral shapes, e.g. the distinct spectrum of sound "z" from different speakers. In this paper, we implemented a speaker recognition system using GMM on Mel-Frequency Cepstrum Coefficients (MFCCs) with preprocessing processes. We tested our system with TIDIGITS data set (325 speakers), real recordings from 12 speakers from our own lab, 50 persons in Nasur company and 150 persons in India and achieved 100% correct recognition rate. Moreover, our experiments on participants speaking different languages during training and testing show that this scheme is even language independent.

7708-04, Session 1

A new approach for sclera vein recognition

L. Thomas, Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States)

Among biometric researchers, increasing the operational capabilities of iris and ocular-region recognition has been a major focus of recent research. Examples include performing iris recognition under non-compliant or less constrained conditions, off-angle iris recognition, and iris recognition using visible frequency illumination. In all of these cases, the use of sclera vein patterns as a biometric, either alone or in conjunction with the iris, has the potential to significantly increase the accuracy and efficiency of human identification. In this paper, we present a new approach for sclera segmentation, sclera vein enhancement, sclera feature extraction, and sclera pattern registration and matching. The approach was tested using the UBIRIS database - a noisy database acquired using visible frequency illumination to demonstrate the practical application of this new approach with less-than-ideal data.

7708-05, Session 1

A new approach for multiple wavelength-based iris recognition

Z. Zhou, Y. Du, Indiana Univ.-Purdue Univ. Indianapolis (United States); E. J. Delp III, Purdue Univ. (United States)

Among biometrics, iris recognition has been tested to be one of the most reliable approaches for positive human identification. Currently, most iris recognition algorithms are designed for use with near-infrared images. Using existing algorithms, iris recognition under visible frequency is possible, but does not achieve very high accuracy. In this paper, we develop a new approach for multiple wavelength based iris recognition, which can extract iris features from different wavelengths efficiently and fuses the iris feature information together for accurate recognition. The experimental results show that the proposed method is promising.

7708-06, Session 1

Palm print identification

D. R. Kisku, BCREC (India); P. Gupta, Indian Institute of Technology Kanpur (India); J. K. Sing, Jadavpur Univ. (India)

The fundamental issue in palmprint verification is finding a proper feature descriptor to represent its overall structure and its line patterns. Physiological structure of palmprint consists of different types of features including principal lines, wrinkles and creases, and principal lines composed of heart line, head line and life line. In palmprint verification and identification, locations of these physiological features are important for individual. These principal lines and their shapes change little over time. It has been estimated that the wrinkles are much thinner than the principal lines and much more irregular. Palmprint verification and identification systems are proved to be a unique, reliable and robust biometric characteristic with high recognition accuracy. Quest for more reliable biometric systems with accurate performance, palmprint systems are attracted much public attention. Due to several advantages, such as non-intrusiveness, low-resolution imaging, user-friendly, low price palmprint devices and setup, stable and distinct features made palmprint systems more usable to users. In this paper, we present a palmprint identification system using SIFT features and Lagrangian network graph technique. We extract region of interest (ROI) from wide palm texture in preprocessing stage and we then employ SIFT feature extraction from palmprint images, whereas only the ROI is considered for invariant points extraction. Finally, identity is established by finding permutation matrix for a pair of reference and probe palm graphs drawn on extracted SIFT features. Permutation matrix is used to minimize the distance between two graphs. Permutation matrix constraints are formulated quite naturally in the framework of deterministic annealing. The row or column constraints are winner-take-alls (WTAs). The graph matching distance allows us to express the combination of the distance measure and the permutation matrix constraint using Lagrange parameters. The experimental results computed on CASIA and IITK palmprint databases

show the effectiveness and robustness of the proposed palmprint verification system while scale and rotation invariant SIFT operator is used for feature extraction.

7708-07, Session 1

Human action recognition based on multiple types of features

R. Minhas, A. Baradarani, S. Seifzadeh, J. Wu, Univ. of Windsor (Canada)

This paper introduces a novel supervised learning framework for human action recognition using hybrid features. The hybrid features consist of spatio-temporal and local static features extracted using motion-selectivity attribute of 3D dual-tree complex wavelet transform (3D DT-CWT) and affine SIFT local image detector respectively. Shift-invariance and motion selectivity properties of 3D DT-CWT support reduced artifacts and resourceful processing of a video for better quality and well-localized detection of spatio-temporal features while Static local features are determined using affine SIFT descriptors. Visual vocabularies constructed using both kinds of features are input to an extreme learning machine (ELM) that offers classification at considerably higher speed in comparison with other learning approaches such as classical neural networks, SVM and AdaBoost to name a few. The proposed learning model offers two core advantages: 1) The framework is significantly faster than traditional approaches due to volumetric processing of images as a `3D box of data' instead of a frame by frame analysis, 2) rich representation of human actions in terms of reduction in artifacts in view of the promising properties of our recently designed full symmetry complex filter banks with better directionality and shift-invariance properties. . Our proposed method outperformed state-of-the-arts schemes and does not rely on any assumptions about scene background, location, object of interest, or point of view information. Both military and industrial applications can potentially benefit from our recognition framework because of its real-time processing and improved precision compared with other well-established schemes.

7708-08, Session 1

Fusion strategies for boosting cancelable online signature verification

D. Muramatsu, Seikei Univ. (Japan); M. Inuma, National Institute of Advanced Industrial Science and Technology (Japan); J. Shikata, Yokohama National Univ. (Japan); A. Otsuka, National Institute of Advanced Industrial Science and Technology (Japan)

One drawback of cancelable approaches is that the performance is inferior to that of non-cancelable approaches. For one solution, we propose a scheme to boost the performance of a cancelable approach for online signature verification.

General cancelable systems transform a biometric data set using a key and use a transformed data for verification. On the other hand, our proposed cancelable system uses two keys and transforms one biometric data set into two transformed data sets.

There are two phases in the proposed system, an enrollment phase and a verification phase. In the enrollment phase, two keys (the first and second key) are selected by a system, and two transformed data sets are generated from a biometric data set using the first and second keys separately. A feature set is extracted from each transformed data set; therefore, two feature sets are generated and enrolled separately as reference data sets.

In the verification phase, a user input a biometric data together with two keys. The biometric data are transformed by using the input keys, and two feature sets are extracted from the transformed data sets. These two feature sets are compared with the associated reference data sets, and two scores computed from these features are combined using fusion strategy for verification. We consider several fusion strategies and

compare the performance of the strategies in this paper. The experiments were performed a distance-based online signature verification algorithm with a convolution based transformation. The experimental result showed that proposed system is promising.

7708-09, Session 2

A new approach for cancelable iris recognition

K. Yang, Y. Sui, Z. Zhou, Y. Du, X. Zou, Indiana Univ.-Purdue Univ. Indianapolis (United States)

Iris has been tested to be a stable and reliable biometric for positive human identification. However, traditional iris recognition schemes raise several privacy concerns. One primary concern is that the iris pattern of an individual is permanently bound with him/her and cannot be changed. Hence, once it is stolen, this biometric is lost forever as well as all the applications where this biometric is used. Thus, new methods are desirable to secure the original pattern and ensure its revocability and alternatives when compromised. In this paper, we propose a novel scheme which incorporates with iris features into key generation to achieve "cancelability" and at the same time does not reduce iris recognition accuracy.

7708-10, Session 2

Visual words for lip-reading

A. B. Hassanat, S. A. Jassim, Univ. of Buckingham (United Kingdom)

In this paper, the automatic lip reading problem is investigated, and an innovative approach to solve this problem is proposed. This VSR approach, termed "visual words", depends on the signature of the word itself, rather than the Visemes involved in the word. We also propose a hybrid feature extraction method dependent on geometric, appearance, and image transform features.

The system consists of two parts, 1) Feature extraction/selection, and 2) Visual speech feature recognition. After localizing face and lips, several visual features of the lips are extracted, (e.g. height and width of the mouth, mutual information, and quality measurement between the DWT of the current ROI and the DWT of the previous ROI, the amount of the red colour in ROI representing the appearance of the tongue and teeth). Each spoken word is represented by 8 signals, one for each feature. Those signals maintain the dynamic of the spoken word, which contains a good portion of information. The system is then trained on these features using the KNN and DTW.

This approach has been evaluated using a large database for different people, and large experiment sets, The evaluation has proved the visual words superiority over the traditional visemic approach, which researchers used to use for this kind of problems.

7708-11, Session 2

A novel key management scheme using biometrics

Y. Sui, K. Yang, T. Lu, Y. Du, X. Zou, Indiana Univ.-Purdue Univ. Indianapolis (United States)

Key management is one of the most important issues in cryptographic systems. Several important challenges in such a context are represented by secure and efficient key generation, key distribution, as well as key revocation. Addressing such challenges requires a comprehensive solution which is robust, secure and efficient. Compared to traditional key management schemes, key management using biometrics requires the presence of the user, which can reduce fraud and protect the key better. In this paper, we propose a novel key management scheme using

iris based biometrics. The analysis of its security and performance and comparison with existing schemes (along with the experimental results) show that

our newly proposed scheme outperforms traditional key management schemes as well as some existing key-binding biometric schemes in terms of accuracy, computational complexity and/or security.

7708-12, Session 2

Improving the accuracy and security of fingerprint biometric system using enhanced image fusion

S. Alsharif, A. El-Saba, Univ. of South Alabama (United States)

Fingerprints recognition systems have been widely used by financial institutions, law enforcement, border control, visa issuing, just to mention few. Biometric identifiers can be counterfeited, but considered more reliable and secure compared to traditional ID cards or personal passwords methods. Fingerprint pattern fusion improves the performance of a fingerprint recognition system in terms of accuracy and security. This paper presents a digital enhancement and fusion approaches that improve the biometric accuracy and security of fingerprint recognition system. It is a two-step approach. In the first step raw fingerprint images are enhanced using high-frequency emphasis filtering (HFEF). The second step is a simple linear fusion process between the raw images and the HFEF ones. It is shown that the proposed approach increases the accuracy and security of the fingerprint biometric recognition system, where any improvement is justified using the receiver operator characteristic (ROC) curve concept.

7708-13, Session 2

Using FPGAs to implement secure identity management on constraint devices

T. Kuseler, H. Sellahewa, S. A. Jassim, Univ. of Buckingham (United Kingdom)

The use of mobile communication devices with advanced capabilities and multiple sensors is growing rapidly. Such ubiquitous devices are essential tools in today's globalised economic activities enabling anywhere-anytime financial and business transactions. Cryptographic functions and biometric-based authentication can enhance the security and confidentiality of mobile transactions. Biometric template security, real-time biometric-based authentication and efficient memory management are key factors for successful identity management solutions, but seriously challenging to implement in real-time on mobile devices that are constrained by memory and processing power. The SecurePhone EU funded project yielded a prototype mobile communication device with a multi-biometric user authentication system that complements PKI and enables secure transactions between two connected parties. However, the use of the phone's SIMcard as a secure alternative to the device's processor has resulted in significant increase in verification time (from 1 second to 54 minutes) which was resolved at the expence of much reduced accuracy. This paper is concerned with the use of FPGAs to enable secure identity management solutions for SecurePhone-like devices. FPGAs offer a low-cost, secure, flexible, high-performance technology suitable for such devices. This study investigates the various ways in which cancellable biometric-based identity management applications can benefit from FPGA-based solutions. In particular, we shall exploit the reconfigurable computing on FPGAs to test the viability of multiple cancellable versions of face biometric to authenticate owner of the devise for different applications. We shall test the runtime complexity in terms of the number of applications.

7708-14, Session 3

Multiple template-based image matching using alpha-rooted quaternion phase correlation

S. P. DelMarco, BAE Systems (United States)

In computer vision applications, image matching performed on quality-degraded imagery is difficult due to image content distortion and noise effects. State-of-the art keypoint based matchers, such as SURF and SIFT, work very well on clean imagery. However, performance can degrade significantly in the presence of high noise and clutter levels. Noise and clutter cause the formation of false features which can degrade recognition performance. To address this problem, previously we developed an extension to the classical amplitude and phase correlation forms, which provides improved robustness and tolerance to image geometric misalignments and noise. This extension, called Alpha-Rooted Phase Correlation (ARPC), combines Fourier domain-based alpha-rooting enhancement with classical phase correlation. ARPC provides tunable parameters to control the alpha-rooting enhancement. These parameter values can be optimized to tradeoff between high narrow correlation peaks, and more robust wider, but smaller peaks. Previously, we applied ARPC in the radon transform domain for logo image recognition in the presence of rotational image misalignments. In this paper, we extend ARPC to incorporate quaternion Fourier transforms, thereby creating Alpha-Rooted Quaternion Phase Correlation (ARQPC). We apply ARQPC to the logo image recognition problem. We use ARQPC to perform multiple-reference logo template matching by representing multiple same-class reference templates as quaternion-valued images. We generate recognition performance results on publicly-available logo imagery, and compare recognition results to results generated from standard approaches. We show that small deviations in reference templates of same-class logos can lead to improved recognition performance using the joint matching inherent in ARQPC.

7708-15, Session 3

Nonlinear filtering for image enhancement using alpha-trimmed mean decomposition

Y. Zhou, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

Digital images are generated by imaging devices or systems such as digital camera. They sometimes show over- or under-exposed regions when it is obtained in some critical environmental conditions such as sunny or cloudy days. The image may be also acquired in particular unfavorable conditions such as in presence of smoke or fog. In those cases, images may lost some critical information or show poor resolution of objects and details [1]. Image enhancement is an effective and powerful tool to improve visual quality of images by increasing global contrast of images or local contrast between regions or objects and their background surroundings.

Many enhancement techniques have been developed recently to improve the contrast of image. Nonlinear filtering shows more robust characteristics for suppressing noises and preserving edges and details. Many types of nonlinear filters have been widely used for image enhancement. Examples includes adjustable quadratic filter [2], adaptive filtering [3, 4], recursive rational filter [5], Tree-Structured Nonlinear Filter [6], and fuzzy domain based recursive lowpass filtering [7]. Image decomposition has been used for image enhancement by multiscale representation in the wavelet domain [8-10]. The mean-separate technique combined with histogram equalization for image enhancement is called bi-histogram equalization [11]. This enhancement method intends to preserve the mean brightness of original image.

In this paper, we introduce a new image enhancement algorithm by integrating the nonlinear filtering with image decomposition. The algorithm first decomposes the original image into two sub-images using the alpha-trimmed mean as a threshold. The sub-images are then filtered by the nonlinear filtering operation separately. The resulting enhanced

image is obtained by combining two filtered sub-images. Benefited from the nonlinear filtering, the new enhancement algorithm can improve the global contrast of the original images and also the visual quality of the specific regions or objects while reducing the noises. It has potential applications in object segmentation and recognition.

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7708-16, Session 3

Biometric person authentication method using features extracted from pen-holding style

Y. Hashimoto, D. Muramatsu, H. Ogata, Seikei Univ. (Japan)

People need to hold a pen with a hand to write a signature or something on a paper. The manner of holding pen is distinctive among persons. Therefore, pen-holding style can be useful for person authentication.

In this study, we propose a biometric person authentication method using features extracted from pen-holding style. There are two phases in the proposed system, an enrollment phase, and a verification phase.

In the enrollment phase, several images of pen holding style are captured by a camera placed to the side of the writing hand. Several features are extracted from the images. We consider features such as pen inclination information, a thumb position, a pen tail position, and many other features related to the pen holding style in this paper. A thumb position and a pen tail position are detected by using a template matching technique, and features related to the pen holding are calculated using the extracted hand region. These extracted features are enrolled as a reference data set.

In the verification phase, an image of pen holding style is captured and the same features are extracted from the image. The extracted features are compared with a reference data set, and several dissimilarity scores are computed independently. These dissimilarity scores are combined and one verification score is calculated by using fusion model. A three-layer perceptron is used as a fusion model in this paper. Preliminary experiments were performed by using a private database. The experimental results show that the proposed system is promising.

7708-17, Session 3

A clustering-based video similarity measure and its application to human action recognition

Q. Jiang, Y. Chen, HRL Labs., LLC (United States)

Computing the similarity between videos is a challenging problem in many applications of video processing such as video retrieval and video-based action recognition. The main difficulty in evaluating similarity between videos is the lack of an effective distance measure. In this paper, we propose a clustering based distance measure to solve this problem. In our approach, a video sequence is represented by a set of spatiotemporal descriptors. Therefore computing the similarity between two video sequences can be achieved by estimating the distance between two sets of descriptors extracted from the videos. To compute the distance measure, we use clustering to obtain distributions and "constrained distributions" of the two sets of descriptors, and use the Kullback-Leibler (KL) divergence with the distributions. We apply our distance measure to the problems of distinguishing different human actions and content-based video retrieval. Our experimental results show that the proposed distance measure is an effective metric for these applications.

7708-18, Session 3

Wavelet-based image quality/noise self-measurement

N. Al-Jawad, S. A. Jassim, Univ. of Buckingham (United Kingdom)

Noise in general is considered to be degradation in image quality. Moreover image quality is measured based on the appearance of the image edges and their clarity. Most of the applications performance is affected by image quality and level of different types of degradation. In general measuring image quality and identifying the type of noise or degradation is considered to be a key factor in raising the applications performance, this task can be very challenging.

Wavelet transform now a days, is widely used in different applications. These applications are mostly benefiting from the wavelet localisation in the frequency domain. The coefficients of the high frequency sub-bands in wavelet domain are represented by Laplace histogram. In this paper we are proposing to use the Laplace distribution histogram to measure the image quality and also to identify the type of degradation affecting the given image.

Image quality and the level of degradation are mostly measured using a reference image with reasonable quality. The discussed Laplace distribution histogram provides a self testing measurement for the quality of the image. This measurement is based on constructing the theoretical Laplace distribution histogram of the high frequency wavelet sub-band. This construction is based on the actual standard deviation, then to be compared with the actual Laplace distribution histogram. The comparison is performed using histogram intersection method. All the experiments are performed using the extended Yale database.

7708-19, Session 3

Activity-based video indexing and search

Y. Chen, Q. Jiang, S. Medasani, D. L. Allen, HRL Labs., LLC (United States)

We describe a method for searching videos based on the activity contents present in the videos. Being able to search videos based on the contents (such as human activities) has many applications such as security, surveillance, video filtering on the internet for content exclusion (such as pornography) or copyright enforcement.

A video search system usually contains two parts, descriptor generation and indexing scheme. Descriptors are extracted from the videos to represent the video contents (in our case, the activities), and the indexing scheme allows us to file videos in an efficient way so that we can find videos containing similar activity contents in a large video database in a very short time.

Conventional video content-based retrieval (VideoCBR) systems are either feature based or semantics based, the former does not try to understand the video contents, and the latter relies on fully understanding the video contents. Neither has been very successful.

Our approach is inspired by the success of visual vocabulary of "Video Google" by Sivic and Zisserman, and especially the work of Nister and Stewenius who showed that building a visual vocabulary tree can improve the performance in both scalability and retrieval accuracy for 2-D images. We apply visual vocabulary and vocabulary tree approach to video descriptors, and take advantage of the discrimination power of these descriptors as well as the scalability of vocabulary tree for indexing. Furthermore, this approach does not rely on any model-based activity recognition. In fact, training of the vocabulary tree is done off-line using unlabeled data with unsupervised learning. Therefore the approach is widely applicable. Experimental results using standard human activity recognition videos will be presented.

7708-20, Session 3

Biometric intra-template variability modeling and adaptation using quality measures

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Biometric recognition schemes are often affected by high intra-class variability due to several factors such as quality of acquisition sensor (e.g. optical, web camera, thermal), environmental (e.g. lighting conditions, dry or wet fingers), behavioural (e.g. change face expression or pose, partial fingerprints). Template aging is another factor that causes large intra-template variability. To overcome these problems many systems store multiple templates and/or updated regularly in order to account for such variations during enrolment stage. The number and nature of selected templates are among the most performance influencing factors. In this paper, a novel offline approaches are proposed for intra-template variability modelling and adaptation. The first one models significant variability and characteristics in biometric data by selecting a number of templates from a large set of biometric images. A batch of successfully matched biometric samples during system operation is used by a second approach to update the stored templates of each individual. These approaches use clustering methods to group different quality biometric samples into different clusters based on the quality information provided by quantitative image quality measures. Depending on the form and the size of each cluster, we exploit representative selection methods in adaptive manner to select one or more prototype templates. We will also propose ways by which biometric recognition systems automatically specify the number of necessary templates for each individual at current biometric signal and/or system quality conditions.

7708-21, Session 4

Automated detection of semagram-laden images using adaptive neural networks

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Digital steganography is gaining wide acceptance in the world of electronic copyright stamping. Digital media that are easy to steal, such as graphics, photos and audio files, are being tagged with both visible and invisible copyright stamps (known as digital watermarking). However, these same techniques can also be used to hide communications between actors in criminal or covert activities. An inherent difficulty in detecting steganography is overcoming the variety of methods for hiding a message and the multitude of choices of available media. Another problem in steganography defense is the issue of detection speed since the encoded data is frequently time-sensitive. When a message is visually transmitted in a non-textual format (i.e., in an image) it is referred to as a semagram. Semagrams are relatively easy to create, but very difficulty to detect. While steganography can often be identified by detecting digital modifications to an image's structure an image-based semagram is more difficult because the message is the image itself. The work that will be presented describes the creation of a novel, computer-based application, which uses hierarchical neural network architectures to detect the likely presence of a semagram message in an image. The prototype system was used to detect semagrams containing Morse Code messages with over 80% accuracy. Based on the results of these experiments our approach provides a significant advance in the detection of complex semagram patterns. Specific results of the experiments and the potential practical applications of the neural network-based technology be will discussed.

7708-22, Session 4

Steganalysis of packet level VoIP steganography

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We present a very successful, new steganalysis method for detecting steganography in VoIP (Voice over IP) calls. VoIP represents a significant opportunity for hiding secret messages. As such, VoIP also represents a significant need for effective steganalysis.

In recent work, Mazurczyk, et. al. describe VoIP steganographic techniques called LACK and HICCUPS where two users, say Alice and Bob, engage in a VoIP call. Alice uses steganographic techniques to send hidden information, either to Bob directly or to another confederate, Carol, who can sniff packets in the network. LACK steganography works by intentionally delaying packets; HICCUPS uses false checksums. Alice replaces the voice payload in these packets with steganographic data. In both methods, Bob ignores the packets "bad" packets and decodes the rest as the VoIP call. Bob and/or Carol can extract the hidden data from these ignored packets.

Our work describes a new steganalysis method to detect LACK and HICCUPS. We make the assumption that the stego-data appears random, because it is compressed or encrypted. Our idea is to approximate the entropy of each packet by estimating the coding length required to losslessly encode the packet. Our algorithm processes all the samples in the VoIP packet, updates the number of bits required to encode then updates the counts for the next symbol. It is fast, easy to implement and highly successful, achieving an approximately 88% true positive rate at a 0.002% false positive rate on voice samples compressed via G.711, a widely supported voice encoding standard.

7708-23, Session 4

Enhanced audio steganography method using adaptive windowing technique

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Audio steganography is a form of data communications used to transmit covert information by selectively modifying audio signal data that remains undetected by the human auditory system (HAS). To be effective, this audio based communications channel must be resistant to common attacks against stegonographic channels. In this paper, we describe a novel approach to audio data embedding which is immune to common LSB modification attacks. We will also describe how this new embedding algorithm can be used as a robust digital watermarking system for use with the popular WAV file format. We introduce a high speed adaptive audio data windowing technique which takes advantage of full spectrum data spreading to achieve high capacity embedding while maintaining fully robust watermarking characteristics.

7708-24, Session 4

SVD-based robust watermarking using fractional cosine transform

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The success and explosive growth of the internet technologies, some of very imperative issues for multimedia data such as illegal copying, distribution, editing, copyright protection, authentication etc become very easy. Recently, steganography has identified as a possible solution of these issues. Steganography is the art of covered (secret) writing (graphy) and typically relates to covert point to point communication between two parties. As a result, steganographic methods are either not robust or having limited robustness against modification of the multimedia data, occurred during transmission, storage or file conversion. As a possible solution to overcome robustness problem of steganography, Digital Watermarking terminology is developed and has drawn much attention of the research community. Thus, rather than steganography, watermarking is used where ever the protection of media is concerned. Digital watermarking is a technology to insert one or more information (the watermark) into a multimedia, which can be later extracted or detected for variety of purposes including identification and authentication purposes. The multimedia which has to be protected is called cover-data. The embedding is done in such a way that it must not cause serious degradation to the original multimedia.

In this paper, a robust watermarking technique based on fractional cosine transform and singular value decomposition is presented to improve the protection of the images. A meaningful gray scale image is used as watermark instead of randomly generated Gaussian noise type watermark. First, host image is decomposed by the means of fractional cosine transform. Now, the positions of all frequency coefficients changed with respect to some rule and this rule is secret and only known to the owner/creator. Then inverse fractional cosine transform is performed to get the reference image. Watermark logo is embedded in the reference image by modifying its singular values. For embedding, the singular values of the reference image are found and then modify it by adding the singular values of the watermark image. A reliable watermark extraction algorithm is developed for extracting watermark from possibly attacked image. Fractional cosine transform depends on the transform order (along all axis) to decompose and reconstruct the image. The value of transform order is used as a key in the proposed scheme because without knowing transform order, one cannot make the reference image and hence cannot extract the watermark correctly. Hence, the security of proposed scheme is increased. For changing the positions of frequency coefficients, space filling curve is used. Space Filling Curve (SFC) is a continuous mapping which traverses every point in a space, in a particular order, according to some algorithm. In this paper, a new space

filling curve is introduced, namely Saw-Tooth space filling curve and also used for changing the frequency coefficients position. Experiments are done on different standard gray scale images and robustness is carried out by a variety of attacks.

7708-25, Session 4

Image encryption using Sudoku Matrix

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Computer and network technologies have been well-developed and widely applied in many different areas such as email services, online music and movies, remote video conference, and many other applications. These applications bring a lot of benefits and conveniences for people all over the world to access and share information. In order to improve the health services and reduce the cost, medical institutions and hospitals usually store, and share medical images and patient's records over networks among the laboratories, medical service centers and doctors. On the other hand, these multimedia data with important private information might be vulnerable for the unauthorized accesses and attacks. Image encryption is one effective method to protect multimedia data by transforming them into an unrecognizable format.

Many different image encryption algorithms have been developed in recent years. The algorithms are mainly based on the transform/ frequency domain or the spatial domain. In transform domain encryption, images are first transformed to the frequency domain using a specific transform; encryption algorithms then scramble or encrypt the transform coefficients or blocks; finally encrypted images will be obtained by transforming processed images back into the spatial domain using an inverse transform. Dang et al. proposed an encryption approach based on Data Encryption Standard (DES) algorithm in the Discrete Wavelet Transform[1]. Tang et al. shuffled the DCT coefficients within an 8 by 8 block for JPEG images or MPEG videos [2]. On the other hand, the encryption, algorithm based on the spatial domain directly modifies image pixel values or locations. This encryption approach is able to protect images or videos with a desired level of security while preserving quality of images/videos. Fridrich et al. employed a 2D chaotic baker map for image encryption[3]. Zou et al. applied a classical Fibonacci number to scramble images [4]. Zhang et al. used the discrete Chebyshev chaotic sequences for image encryption[5].

Sudoku is a logic-based, combinatorial number-placement puzzle [6]. Recently, it has been used for data hiding. Shirali-Shahreze et al. applied Sudoku solutions for encrypting short message service (SMS) [10]. They used a 9 by 9 Sudoku matrix and hided data in one row or one column of the puzzle. Chang et al. used a expanded matrix based on one selected 9 by 9 Sudoku solution as a reference matrix to guide cover pixels' modification for embedding secret data as a modification on Mielikainen's Least Significant Bit (LSB) matching method[11]. Later, Hong et al [12, 13] improved Chang's approach by applying the searching idea of minimal Euclidean distance.

In this paper, we introduced a new image encryption algorithm based on Sudoku Matrix. The algorithm uses 1D Chaotic Logistic Map to generate a random decimal sequence using parameters. This sequence is then used to build a Sudoku matrix which is a reference matrix in the new presented algorithm. In the Sudoku matrix, none of any two equal-valued elements in one block will be aligned in the same row, column or box. This property can be used for image encryption such that any two pixels in the same box in the original image will be transformed into completely different boxes in the encrypted image. Furthermore, the algorithm can change the pixel values so that the encrypted image has an approximately equalized histogram.

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7708-26, Session 5

Region-of-interest-based bit-allocation scheme for H.264/AVC

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This paper presents a new Region-of-Interest (ROI) based bit-allocation scheme for advanced video coding (H.264). We use a group-of-picture (GOP) structure to compensate bits consumption between I (intra) and P (inter) frames in one GOP, and simultaneously adjust the quantization parameter (QP) for each macroblock, according to the region-of-interest on I or P frames, respectively. Our algorithm is implemented on the H.264/AVC codec JM14.0 and totally compatible with existing H.264/AVC decoders. The experimental results show that compared to the standard JM14.0 encoder, under the same bitrate budget, the proposed algorithm achieves a subjective visual quality improvement as well as an objective PSNR gain. The ROI-based bit allocation scheme has a potential to low-bitrate and real-time video applications, such as video conferencing and mobile TV broadcasting.

7708-27, Session 5

Compressive sensing in block-based image/video coding

B. Han, J. Xu, D. O. Wu, J. Tian, H. Yu, Univ. of Florida (United States)

Recently, a new theory compressive sensing has been proposed as a more efficient sampling scheme for sparse signals. Comparing to the traditional Nyquist-Shannon sampling theory, compressive sensing provides a great reduction of sampling rate, power consumption and computational complexity to acquire and represent a sparse signal. In this paper, we focus on using compressive sensing in block based image/video compression schemes, such as JPEG and H.264. In the traditional lossy coding schemes, most of the error is caused by quantization. In our experiment, compressive sensing recovery can help mitigating the quantization error in the decompression process and achieve 1 dB gain over standard JPEG.

7708-28, Session 5

Block-based method for real-time compound video compression

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In this paper, we propose a novel compound video compression method for real-time applications of computer screen video transmission. The compound video is a very special kind of video, which usually has less motion and contains a mixture of text, graphics, and natural pictures in each frame. A variety of algorithms has been proposed for compound image compression, which tries to remove the spatial redundancy of a single image. However, few works have addressed the problem of compound videos compression. Therefore, we review the previous works on compound image compression and discuss how to extend the existing algorithms to traditional video compression. Then we propose our system framework based on H.264. In order to improve the visual performance and network efficiency, we also propose an adaptive quantization algorithm and a rate control algorithm for compound video compression. The experiment results show that the new compression method is able to compress the compound video in real-time with a relatively low computational complexity. With the motion compensation, the visual quality of the compound video is much better than simple compound image compression.

7708-29, Session 5

The control roots of latency information theory

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Recently a novel latency theory was found to naturally arise as the certainty time dual of uncertainty space information theory. This latency theory has been successfully applied to real-world radar systems as demonstrated in a companion paper. While information theory addresses information efficiency issues linked to the sourcing, for communication purposes, and retention, for recognition reasons, of information, latency theory addresses latency efficiency issues linked to the moving, for communication purposes, and processing, for recognition reasons, of information. In this paper, it will be demonstrated that latency-information theory has its roots in a 'Matched Processors (MP)' quantized controls methodology first formulated in the late 1970's. MP offers an alternative to Bellman's Dynamic Programming (DP) for quantized controls that does not suffer of the 'curse of state dimensionality' of DP. The MP scheme addresses in two independent steps the design of a state estimator and a state controller for a controlled system that is modeled with generally non-linear stochastic state-equations. In the first step of the MP procedure information theory ideas, e.g. a Kalman estimator or a more general MMSE predictive transform estimator (PTE), are used to estimate the noisy state of the controlled system. While on the second MP step latency theory ideas are used to design a state controller under the assumption that the system state is perfectly known. The scheme will be illustrated using, for instance, a servomechanism control example.

7708-30, Session 5

On the revelation of a thermodynamics bridge for latency information theory

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While information theory addresses information efficiency issues linked to the sourcing, for communication applications, and retention, for recognition applications, of information, latency theory addresses latency efficiency issues linked to the moving, for communication applications, and processing, for recognition application, of information. In this paper, it will be shown that the mathematical source-entropy H in bit units and a novel physical retainer-entropy N in squared meter units of information theory and the mathematical processor-ectropy K in binary operator

(bor) units and novel physical mover-ectropy A in second units of latency theory are inherently bridged by the Boltzmann thermodynamic entropy S. These theoretically exact as well as practical results will be illustrated with real-world applications.

7708-31, Poster Session

Knowledge-unaided power-centroid adaptive radar and latency information theory

E. H. Feria, College of Staten Island (United States)

Knowledge-unaided power-centroid (KUPC) is a novel adaptive radar technique. The KUPC radar problem treated in this paper addresses the detection of moving targets by an airborne moving target indicator (AMTI) radar system while subjected to severe environmental disturbances. This problem was motivated by the 2001-2004 KASSPER Program of DARPA. For this program under a university grant a MMSE predictive-transform (PT) compression algorithm was developed for clutter prior knowledge in the form of a set of 4MB 1024x256 samples SAR imagery of the earth where each image represents terrain of approximate dimensions of 1,400 by 1,800 meters. As a result of basic research work done on the signal processing aspects of the KASSPER system leading to the development of a novel latency-information theory, it was found that SAR imagery can be compressed by a factor of 8,172 while yielding a SINR performance that is approximately 1dB away from that of an optimum system. The fundamental enabling idea behind this novel radar technique was the evaluation of the power-centroid of each range-bin that is derived from the clutter prior knowledge. However, recently it has been shown that the prerequisite power-centroid of each range-bin could instead be derived 'on-line' from a sample covariance matrix. This unexpected result is highly desirable since extensive Matlab simulations have shown that without the use of SAR imagery as prior knowledge approximately the same SINR performance is derived as when they are used as prior knowledge. It is expected that the proposed methodology can be readily extended to more complex radar scenarios and/or can be adapted to other types of adaptive signal processing problems. The KUPC algorithm and Matlab program simulating it are discussed in this paper.

7708-32, Poster Session

Security issues in convergence of wireless technologies

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The wireless space has seen convergence of many technologies to give a rich media experience to users. The paper looks into security issues in convergence of wireless technology in general and provides insight into various forms of convergence. These include functional, technology, economic, political and geographical. Some of the prominent technologies in mobile and wireless sectors brought out by convergence have been discussed along with the benefit that can be derived with convergence of WiFi and WiMAX system.

However, the convergence of wireless technologies can provide immense benefit to the user who can then have seamless high speed WiFi connection while on the move. User can have all services available in WiFi mode. For example, it can be made cheap long distance calls using VoIP over WiFi connection; it can be watched video while on the move as well as surf Internet. Thus, we can say that convergence of WiFi with WiMAX will provide users with benefits of both worlds i.e. high speed connectivity of a LAN as well as mobility of WiMAX.

These advantages are the main driving force for convergence. The advantages may be due to lower cost, easier management, less maintenance, fewer interface, fast provisioning, newer and improved services, and easy user interface. This new technology will greatly improve access, bandwidth and reliability but it may introduce security problems if these not plan in the beginning. In particular routing and malicious node need be guarded against. This paper investigates the security in the wireless convergence and what are the challenges to merge two different security system.

7708-33, Poster Session

An edge detector-based integrated database framework for security applications

S. Veeraraghavan, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

With the recent terrorist attacks across the globe, airports and ports have become important places to enforce stronger security measures to prevent such attacks. This alarming increase in security threats has created a need to have a robust automated threat recognition and detection systems. The goal of such systems is to precisely identify and classify the potential threats in the cargo and passenger luggage. Such system faces the challenges towards the automatic identification of wide varieties of threat objects. Such security application requires efficient Image processing algorithms and involves the processing of voluminous image data to precisely classify the threat objects. To achieve this goal, we need a unique framework where interdisciplinary technologies can work in tandem to address the security concerns.

Image processing approaches like edge detection, segmentation and feature vectors plays an important role in security applications for aviation and cargo. The ability of the database technology to handle voluminous amount of data & their capacity for effective data storage and retrieval makes them an ideal solution to assist the automatic threat detection. This paper proposes an integrated frame work that describes the use of database technology with advanced edge detection techniques for automatic threat detection. The proposed database will contain the feature vectors of potential threat objects, which will be used as baselines for matching against the potential threat objects identified.

Edge detection techniques like Sobel, Prewitt, Roberts and Canny algorithm are widely used for their simplicity. However this derivative based edge detectors produces a lot of false positives for CT baggage images due to its complex nature.This problem creates a need to have a robust and efficient edge detection algorithm.

This paper proposes an improved ratio edge detection algorithm for CT Baggage Images. This algorithm smooths the input image using median filter and calculate the directional derivatives along vertical & horizontal direction as a ratio among the intensity value of current pixel and its adjacent neighbor's. It then applies the non maximal suppression to eliminate the spurious edges. This algorithm uses a new combined adaptive upper threshold and fixed lower threshold technique to generate a better upper and lower bounds for thresholding. The feature vectors of the output edge map will be calculated and compared against the baseline feature vectors stored in the database to identify potential threats. Support vector machine will be used to classify the threat objects.

Test runs were executed over different types of baggage images with different constituent objects. The experimental results indicate that our proposed method outperforms canny algorithm by significantly suppressing the noises & has significantly reduced the false positives. It also has identified most of the essential structures of the baggage's constituent objects by preserving the edge shape.

7708-34, Poster Session

Color-based lip localization method

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A considerable amount of applications that deal with the human face have recently emerged, particularly concerning the lips and mouth area, such as: face detection, face recognition, facial expression recognition, and visual speech recognition. Lip localization is an important research problem for its role as an exigent case of a more general problem, i.e. object detection. This paper is concerned with lip localization for visual

speech recognition (VSR) system.

We shall present an efficient method for localizing human's lips/mouth in video images captured on mobile constrained devices. This method is based on using the YCbCr approach (where lip pixels have high Cr and low Cb) as an initial step. Subsequently, information about the segmented pixels in the ROI around the candidate lips region (including r, g, b, warped hue, Cb, Cr, the X co-ordinate and the Y co-ordinate for each lip-pixel) are used to train the system. The mean is calculated for each propriety, and ROI pixels will be clustered (to lip/non-lip pixel) depending on their distances from the mean vector of the initial segmented lip region.

We shall test the performance of this method using a new-recorded database of 780,000 frames, and demonstrate its efficiency and high accuracy (91.15%) in comparison to existing schemes.

7708-35, Poster Session

Creating Wi-Fi Bluetooth mesh network for crisis management applications

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The needs for creating mesh networks in crisis management situation present a crucial challenge for modern society. Crisis management refers to activities that require immediate response to a disaster, recovery, and preparedness efforts to reduce the impact on normal activities and speed up the processes of recovery and relief.

One of the problems that make rescue operations more challenging is the lack of interoperability between mobile devices available within the vicinity of major accident. Many devices nowadays are equipped with Wi-Fi, Bluetooth, or both technologies. These devices can communicate among themselves using either Wi-Fi or Bluetooth.

In this paper, we aim to create a mesh network consisting of Wi-Fi and Bluetooth devices. When a natural disaster occurs, this proposed mesh network can be used to support rescue and "first aid" response operations by creating a mesh network of Bluetooth and Wi-Fi mobile devices to connect different rescue teams and public agencies together in one environment and possibly exploit the presence of devices held by public users who happen to be in the vicinity of incident.

Devices included in the mesh network act as gateways that connect Bluetooth and Wi-Fi nodes to the outside world. This will be done by creating a link between the media access control (MAC) layer of Wi-Fi and the baseband layer of Bluetooth in the gateway nodes. For testing and evaluation, a combination of mobile devices and desktop computers will be used to construct the proposed network.

7708-37, Poster Session

Combined approach of geometric and orientation features for offline signature verification using committee machines

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Identity verification through offline signature is an important research area in computer vision and pattern classification, where the main objective is to identify or infer of user from signature characteristics. In this paper, a combined approach of geometric features and orientation features has been proposed for offline signature verification. The proposed system uses Bayesian committee machines as a classifier for identity verification. In this study, the geometric global and local features and orientation features are extracted during feature extraction. Prior to feature extraction, to increase the reliability and accuracy of verification performance, some preprocessing operations are applied on the raw signature images. Global features describe the signature as a whole, i.e. the global characteristics of the signature, such as width, height, aspect ratio, horizontal projection, vertical projection, center of gravity,

etc. Global features are less sensitive to signature variation and the effect of noise. Local features are set of features that describe the grid region characteristics of a signature. Gradients, pixel distribution, etc in local segments are considered as local features. Orientation features are extracted in the 8 different directions start from 00 to 1800 with the interval of 22.50. The features are considered as the collection of straight lines along the 8 directions and orientation features are extracted from thinned binary signature. Three sets of features comprises global, local and orientation features are then passed through three Bayesian committee machine experts. Bayesian committee machine experts generate matching scores and further these scores are fused using 'sum' fusion rule. The final score is then checked against a heuristically determined threshold and acceptance or rejection is established. The main purpose of this paper is to report a robust and efficient offline signature verification system and also address the problem of skilled forgery detection efficiently with less computational complexity.

7708-38, Poster Session

Comparative study of histogram equalization algorithms for image enhancement

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Contrast enhancement is a significant technology in different applications in image processing such as medical image analysis, remote sensing, advanced photography and display technology. It helps to reveal details in the picture which may have some artifact and unnatural look, and obtain an informative image[1].

Histogram equalization (HE) is a well-known technique for image enhancement due to its simplicity and effectiveness[2]. It first calculates the occurrences of each intensity value in an image, then flattens and stretches the dynamic range of the histogram based on the probability density function [3]. This process uses a monotonic, non-linear mapping to re-distribute the intensity values of pixels in the image such that the output image contains a uniform distribution of intensities. As a result, HE reserves the median value of the image and increases the dynamic range of the histogram of the image, thus the contrast is highly improved [4]. However, HE has seldom been used in TV and video because it suffers from two disadvantages: over-enhanced high frequency gray level image region and loss of contrast in low frequency gray level image region[5].

Many different methods have been done to overcome these disadvantages. One method combines HE with image decomposition technique. This method decomposes the image into several sub-images and uses HE to enhance them, separately. The basic idea of this method is to preserve the brightness of the original image in different levels. A large number of algorithms have been developed based on this method. Examples includes Minimum Mean Brightness Error Bi-Histogram Equalization[4], Brightness Preserving Bi-Histogram Equalization[5], Human Visual System Based Multi-Histogram Equalization[6], Brightness Preserving Dynamic Histogram Equalization[7], Recursively Separated and Weighted Histogram Equalization[8]. and Equal Area Dualistic Sub-image Histogram Equalization[9]. Another method is based on sub-blocks in the image. This method divides the image into several sub-blocks and apply HE to enhance them, individually. It enhances the image based on the local histograms in different regions in the image. There are a lot of enhancement algorithms based on this method, for example, Partially Overlapped Sub-Block Histogram Equalization[2], and Local Histogram Equalization[10, 11]. The third method is based on transform domain. It first transforms images into frequency domain using different transforms, and then use HE enhancement algorithms to change the transform coefficients [12]. These transforms include Discrete Fourier Transform(FFT), Discrete Cosine Transform (DCT), and Discrete Wavelet Transform (DWT). Algorithms in this field include Logarithmic transform histogram mapping[12] and Logarithmic transform histogram shifting[12].

In this paper, we address a comprehensive review and comparative study of the HE-based enhancement algorithms. We also compare five different HE-based algorithms, namely traditional Histogram Equalization, Brightness Preserving Bi-Histogram Equalization[5], Human Visual System Based Multi-Histogram Equalization[6], Logarithmic transform

histogram mapping[12], Logarithmic transform histogram shifting[12]. The second-derivative-like measure of enhancement (SDME)[13] is used to quantitatively evaluate their enhanced results. Experimental results show that the Logarithmic transform histogram mapping show overall better enhancement performance compared to other four algorithms.

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7708-39, Poster Session

Wavelet transform coefficient histogram-based image enhancement algorithms

J. Xia, K. A. Panetta, Tufts Univ. (United States); S. S. Agaian, The Univ. of Texas at San Antonio (United States)

The goal of image enhancement techniques is to improve the characteristic or visual quality of an image, such that the resulting image is better than the original one, when compared with a specific criteria [1]. Many enhancement techniques have been developed recently to improve the contrast of an image [2]. They can be classified as spatial domain enhancement and transform domain enhancement [3]. One straightforward method for image enhancement is to change the distribution of image histogram in spatial domain such as histogram equalization [ref.]. Image enhancement can also be done by manipulating the coefficient histogram of the Fast Fourier Transform (FFT) [4] or the Discrete Cosine Transform (DCT) [5].

In this paper, we introduce two new image enhancement algorithms based on wavelet coefficient histogram: logarithmic transform histogram matching and logarithmic transform histogram shifting. The histogram matching algorithm first takes an image and applies histogram equalization. Then calculate the logarithmic wavelet transform histogram of the equalized image. The original image would then have its logarithm transform coefficients mapped to match the equalized image's transform histogram coefficients. The histogram shifting algorithm first applies a one-level discrete wavelet transform to decompose an image into a low frequency subband and three high frequency subbands. It then obtains the histograms of the logarithmic magnitude of wavelet coefficients of all subbands. Each histogram is shifted by a shifting parameter. The transform coefficients are then mapped into the shifted histograms. The inverse wavelet transform is finally applied to the exponentiation of the resulting transform coefficients with their original phase for each subband to obtain the enhanced image. By shifting the low frequency subband, the dynamic range of the image has been expanded, while by shifting the high frequency subbands, it can greatly improve contrast and enhance the detail throughout. In our experiment we use an image contrast measure called the second derivative like measure of enhancement (SDME) to evaluate the enhanced images [6]. The experiment results prove that the presented enhancement methods can significantly improve the visual quality of grayscale images and outperform other traditional use of histogram in only spatial domain and histogram matching and shifting based on other transform, such as discrete cosine transform and discrete Fourier transform.

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7708-40, Poster Session

Human visual system-based edge detection algorithms

S. S. Agaian, A. Almuntashri, The Univ. of Texas at San Antonio (United States)

In this paper, we introduce a new HVS-based edge detection algorithm. The new algorithm is based on EPCE contrast enhancement as an input and then deploys controlling edge detection concepts such as Parametric Logarithmic Image Processing (PLIP) and gray-level ratio operations. Also, the introduced algorithm functions in tracking the gradual development of gray-levels in an image. Simulation results have shown the effectiveness of edge detection in certain gray-levels as well as the ability to reject noise belonging to different intensities of gray levels.

Conference 7709A: Cyber Security, Situation Management, and Impact Assessment II

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Cyber Security, Situation Management, and Impact Assessment II

7709A-01, Session 1

Event web, experiential computing, and situational awareness

R. C. Jain, Univ. of California, Irvine (United States)

No abstract available

7709A-02, Session 1

Human-centered information fusion: the emerging role of humans in situation awareness

D. Hall, The Pennsylvania State Univ. (United States)

No abstract available

7709A-03, Session 2

PORTENT: predator aware situation assessment for wireless sensor network surveillance applications

D. S. Ghataoura, Univ. College London (United Kingdom) and SELEX GALILEO (United Kingdom)

In this paper, we propose a distributed predator aware situation assessment system (PORTENT) to model and detect potential events occurring within an uncertain environment. PORTENT draws inspiration from how the mammalian brain detects and assesses signals of threat, within uncertainty, at different speeds. PORTENT represents the faster system using standard signal detection theory and the slower more accurate system as the integration of sensory data over time, until a certain level of confidence is reached. We also consider strategies to how these systems could be combined optimally, to enhance PORTENT situation assessment performance. Our initial experimental evaluation demonstrates the effectiveness of our approach, by improving performance gains by 35% for accuracy, 22% for certainty and 35% for timeliness, thus providing increased information relevancy for situation awareness type applications.

7709A-04, Session 2

Improving situation awareness using a hub architecture for Friendly Force Tracking (FFT)

A. P. Karkkainen, Helsinki Univ. of Technology (Finland)

Situation awareness is the perception of environmental elements within a volume of time and space, the comprehension of their meaning, and the projection of their future status. In a military environment the most critcal elements to be tracked are either friendly or hostile forces. Poor knowledge of locations of frienly forces easily leads into the situation in which the troops could be under firing by own troops or in which decisions in a command and control system are based on incorrect tracking. Thus, Friendly Force Tracking (FFT) is a vital part of building situation awareness.

FFT is basicallly quite simple in theory; collected tracks are shared through the networks to all troops. In the real world, the situation is not so clear. Poor communication cababilities, lack of continuous connectivity n and large number of user on differrent level provide high requirements for BFT systems.

In this paper a simple architecture for friendly force tracking is presented. The architecture is based on NFFI (NATO Friendly Force Information) hubs which have two key features; an ability to forward tracking information and an ability to convert information into the desired format. The hub based approach provides a lightweight and scalable solution, which is able to use several types of communication media (GSM, tactical radios, TETRA etc.). The proposed framework also supports simple configuration and maintanance. One main benefit of the proposed architecture is that it is independent on a message format. It communicates using NFFI messages, but national message formats are also allowed.

7709A-05, Session 2

Task-oriented situation recognition

A. Bauer, Y. Fischer, Fraunhofer-Institut für Informations- und Datenverarbeitung (Germany)

During the last years, video surveillance systems became more and more important. Recently, there are a lot of new developments focused on automated video surveillance which are often dependent on the characteristics of the used sensors. However, for situation recognition, the type of sensors used in the surveillance system should not be relevant, as situations are best described in terms of objects, their attributes and interactions over time. For this reason, in this paper we propose a task-oriented architecture for situation recognition which separates the signal-processing level from the semantic level. The connection between these levels is realized through an abstract description of the task-relevant objects in the surveyed area, the object-oriented world model. As an application of the task-oriented situation recognition approach, an implementation for the detection of abnormal behavior of a person's movement in a building is presented.

7709A-06, Session 3

Toward a theoretical framework for trustworthy cyber sensing

S. Xu, The Univ. of Texas at San Antonio (United States)

The cyberspace is indispensable to the economy and society, but has been ``polluted'' with many compromised computers that can be abused to launch further attacks against the others. Since it is likely that there always are compromised computers, it is important to be aware of the (dynamic) security-related situation in the cyberspace, which is however challenging because the cyberspace is an extremely large-scale complex system. Our project aims to investigate a theoretical framework for trustworthy cyber sensing. Taking the perspective of treating the cyberspace as a large-scale complex system, the core question we aim to address is: What would be a competent theoretical (mathematical and algorithmic) framework for designing, analyzing, deploying, managing, and adapting cyber sensor systems so as to provide trustworthy information or input to the higher-layer of cyber situation awareness, even in the presence of sophisticated malicious attacks against the cyber sensor systems?

7709A-07, Session 3

Attack detection in unattended sensor networks

C. Wu, G. Fry, C. Monnier, Charles River Analytics, Inc. (United States); L. Girod, Massachusetts Institute of Technology (United States); J. Luke, Air Force Research Lab. (United States)

Because sensor networks are often deployed in hostile environments where their security and integrity may be compromised, it is essential to maximize the reliability and trustworthiness of existing and envisioned sensor networks. During operations, the sensor network must be robust to deception, node compromise and various other attacks, while maintaining the operator's situational awareness regarding the health and integrity of the system. To address these needs, we are developing a Framework to Ensure and Assess Trustworthiness in Sensor systems (FEATS) to identify attacks on sensor system integrity and inform the operator of sensor data trustworthiness. The framework provides for three critical functions: attack detection via anomaly detection algorithms including statistical rules and unsupervised learning, probabilistic threat assessment incorporating the current operational context using Bayesian belief networks, and trust management provided by a human-system interface that uses meta-information visualization to portray the trustworthiness of a sensor network. We have performed initial validation of the anomaly detection algorithms by capturing sensor data from an experimental acoustic sensor platform under a number of attack scenarios. The platform, which contains four audio microphones, was exposed to two physical attacks (audio filtering and audio playback) as well as a live replay attack (replaying live audio data that is captured at a remote location), which is analogous to a wormhole attack in the routing layer. With our unsupervised learning algorithms, we were able to successfully identify the presence of various attacks in our preliminary results.

7709A-08, Session 3

An adaptive self-organizing approach to detecting complex distributed attacks in ad hoc networks

J. D. Cannady, Nova Southeastern Univ. (United States)

The growing prevalence and complexity of wireless networks in general and mobile ad hoc networks (MANET) in particular make the effective detection of attacks a critical yet extremely difficult task. The limited bandwidth, lack of centralized processing units, and reduced node-based processing power available to intrusion detection components complicate the process of detecting distributed network attacks. This paper describes an adaptive self-organizing detection approach that is capable of adapting to the particular network environment and detecting both localized and distributed network attacks. The approach leverages simplified neural networks that provide localized analysis of network data, and through the dynamic construction of neural hierarchies, the analysis of larger scale events. The process has been implemented to dynamically adapt to the network environment by emulating the spread of viral agents in biological systems. The neural architectures have been modified to enable the components to establish dynamic connections and modify those connections to enhance the analysis of the available data. The approach is further streamlined by enabling the pruning of ineffective connections and the reinforcement of those neural connections that enhance the analysis process. The resulting lightweight system is capable of detecting network attacks in real-time while minimizing the processing and bandwidth overhead required of the network nodes. A prototype application was developed in MATLAB to validate the approach in a simulated network environment. The results of the series of experiments are provided which serve to demonstrate the potential for the approach. Finally, considerations for future research are also presented.

7709A-09, Session 3

Generation of high-performance protocol-aware analyzers with applications in intrusion detection systems

J. Ros-Giralt, Reservoir Labs, Inc. (United States)

Traditional Intrusion Detection and Prevention (IDP) systems scan packets quickly by applying simple byte-wise pattern signatures to network flows. Such a protocol-agnostic approach can be compromised with polymorphic attacks: slight modifications of exploits that bypass pattern signatures but still reach corresponding vulnerabilities. To protect against these attacks, a solution is to provision the IDP system with protocol aware sensors, albeit at the risk of degrading performance. To balance vulnerability coverage against network performance, we introduce an hardware-aware, compiler-based IDP sensor that leverages hardware engines to accelerate the core functions of protocol parsing and protocol-aware signature evaluation.

The architecture of a high-speed protocol-aware IDP system is fundamentally different from a traditional one because it must be capable of processing packets at a protocol-semantic level. In this paper we introduce a compiler-based architecture designed to generate this kind of system. The compiler, based on BinPAC - the high level declarative language and compiler used by the BRO intrusion detection project - is used to generate the binary specifications of the IDP from a set of high-level protocol and network filter specifications. Our contribution focuses on the design of two high-performance features of the compiler: the processing of regular expressions extracted from a protocol specification and the parallel execution of protocol-aware signatures. The objective of our compiler design is to emit optimized binary specifications capable of offloading both functions (regex and signature processing) onto dedicated hardware DFA engines, providing sensors the function of protocol awareness without the need to sacrifice performance.

7709A-10, Session 3

Cyber protection made easy

E. K. Byamukama, Consultant (Uganda)

One use of the term computer security refers to technology to implement a secure operating system. An example of such a Computer security policy is the Bell-La Padula model. The strategy is based on a coupling of special microprocessor hardware features, often involving the memory management unit, to a special correctly implemented operating system kernel. This forms the foundation for a secure operating system which, if certain critical parts are designed and implemented correctly, can ensure the absolute impossibility of penetration by hostile elements. This capability is enabled because the configuration not only imposes a security policy, but in theory completely protects itself from corruption. Ordinary operating systems, on the other hand, lack the features that assure this maximal level of security. The design methodology to produce such secure systems is precise, deterministic and logical.

Systems designed with such methodology represent the state of the art of computer security although products using such security are not widely known. In sharp contrast to most kinds of software, they meet specifications with verifiable certainty comparable to specifications for size, weight and power. Secure operating systems designed this way are used primarily to protect national security information, military secrets, and the data of international financial institutions.

In this paper systems that can be used on web servers, guards, database servers, and management hosts and that can not only be used to protect the data stored on these systems but also to provide a high level of protection for network connections and routing services will be discussed.

7709A-11, Session 3

Synchronization properties of cyber behaviors

D. Twardowski, G. V. Cybenko, Dartmouth College (United States)

E-mails, web browsing activities, online shopping records, and search query histories are all examples of digital records which may be used to uniquely characterize aspects of an individual's behaviors. In todays technology focused landscape, the electromagnetic spectrum represents the new environment in which we communicate, work, shop, and play, and the cyber behaviors we exhibit there provide a great deal of insight into our individual identities. While cyber-based behavioral modeling is becoming a staple in areas such as e-commerce, security, and finance for its ability to characterize and predict user behaviors, little to no work has been done in the area of behavioral change detection. In this paper we propose an algorithm to sense changes in the behavior of an individual based on their cyber activities. The algorithm can be used in an online manner and we show that it is computationally efficient. A taxonomy of internet sites is pruned according to browsing activity in order to establish a unique identifier of behavior. Dirichlet-Multinomial Bayesian inference is used to infer change in behavior over time and we prove that the accuracy of this inference is bounded. We test this algorithm against a corpus of online browsing records to show its effectiveness in identifying significant changes in behavior. Finally, we discuss how this research may be utilized to greatly enhance work being done in insider threat detection and other security related fields.

7709A-38, Session 3

Novel technology for enhanced security and trust in communication networks

A. Milovanov, L. Bukshpun, R. Pradhan, T. P. Jannson, Physical Optics Corp. (United States)

A novel intelligent technology has been developed to significantly enhance security and trust in communication networks. The technology is based on integration of a novel encryption technique and novel data packet structure with enhanced security tools. The novel data packet structure and encryption technique circumvent all additional data/key encryption, resulting in an unprecedented level of protection against cyber attack that has heretofore been nearly impossible and a very expensive task for conventional communication methods. The developed technology also provides a new trust management feature and detection and classification of cyber attack at the node level. Being employed in communication networks, it provides built-in intelligent features such as self-building, self-awareness, self-configuring, self-healing, and self-protecting capabilities. As a result, networks are able to detect any attempts of intrusion and unauthorized access, evaluate network node trust level, dynamically reconfigure/self-heal, and protect themselves against cyber attacks, thus providing secure and seamless operation. In addition, this developed approach reduces power consumption and computing/communication overhead in networks. This novel technology can be incorporated into any wireless or wired network that requires enhanced security and trust extended to end nodes and also can be applied for secure data storage.

7709A-39, Session 4

Survey of cyber security issues in smart grids

T. Chen, Swansea Univ. (United States)

The future smart grid will enable cost savings and lower energy use by means of smart appliances and smart meters which support dynamic load management and real-time monitoring of energy use and distribution. The introduction of two-way communications and control into power grid introduces security and privacy concerns. This talk will survey the security and privacy issues in smart grids using the NIST reference model, and relate these issues to cyber security in the Internet.

7709A-40, Session 4

Mission driven cyber defense for smart grids

S. J. Yang, Rochester Institute of Technology (United States)

No abstract available

7709A-13, Session 5

Wide area situation awareness in electric power grid

F. L. Greitzer, Pacific Northwest National Lab. (United States)

Major elements of the US energy policy are demand management and efficiency, and renewable sources. Primary drivers are clean energy transmission, reliable energy transmission, and grid cyber security. Development of the Smart Grid seeks to achieve these goals by lowering energy costs for consumers, achieving energy independence and reducing greenhouse gas emissions. The Smart Grid is expected to enable real time "information transparency"-also called wide-area situation awareness (SA)-for operators. Requirements for wide area SA have been identified among interoperability standards proposed by the Federal Energy Regulatory Commission and the National Institute of Standards and Technology to ensure smart-grid functionality. Wide area SA and enhanced decision support and visualization tools are key elements in the transformation to the Smart Grid. The purpose of this presentation is to discuss human factors research needs to promote SA in the electric power grid and the Smart Grid. Topics that will be discussed include the role of human factors in meeting US energy policy goals, the impact and challenges for Smart Grid development, and cyber security challenges. We describe domains of human factors research needs and approaches to human factors research and development. Critical elements of human factors research in this area include viewing the increasingly complex power grid within a system-of-systems framework; the need for user-centered design of wide area SA tools rather than a more traditional technology push of adapting visual graphics techniques to displayable parameters; and application of cognitive engineering methods to facilitate effective design and deployment of visualization tools.

7709A-14, Session 6

Fuzzy logic for determination of crack severity in defense applications

V. K. Sharma, H. Singh, Wayne State Univ. (United States)

Problem of crack detection has attracted the attention of several investigators in the areas like defense, aeronautics, and marine industries. In this paper we suggest fuzzy logic approach for detection of cracks and also deciding about the severity of the crack. The data obtained from data acquisition system is is processed and resulted presented by using various software. Fuzzy rules are developed to determine the severity of the crack and a light controller used to indicate the severity of the crack. The simplicity of the approach makes it very useful in many fields. The steps of the proposed algorithm are as follows:

1. Use data acquisition system for acquiring the data.

2. Analyze the data acquired using software library.

3. Apply Fuzzy Rules for determining the crack severity.

4. Simulate the controller to show the severity of the crack with light indicators of different colors.

7709A-15, Session 6

Incorporating time and spatial-temporal reasoning into situation management

G. Jakobson, Altusys Corp. (United States)

Situation management operates in a space and time, and variety of situation awareness, rapid response and action coordination systems relay extensively on modeling of spatial-temporal relations. There is an increasing demand for those systems in application areas such as tactical command and control of battlefield operations, disaster and emergency situation management, multiple in-vehicle communication, remote underwater and terrain robotics action coordination, and others. All of those applications are characterized by complex sensing of the environment, understanding of the dynamic operational situations, and the capabilities of an agent to act in those situations.

Although the formal methods of reasoning about temporal and spatial relations have gained reasonable interest among the researches, e.g. the work of James Allen on interval logic [1] and the work of Hans Guesgen on qualitative spatial reasoning [2], the practical methods of incorporating them into situation management models and systems have not yet reached satisfactory level.

In this paper we briefly discuss the role of time and spatial-temporal relations in describing the behavior of dynamic systems, review the status of existing research, and present an approach of incorporating spatial-temporal relations into situation management.

In order to give some concrete dimensions to the issues of this paper, we will describe next in the paper two examples of incorporating time and spatial-temporal reasoning into situation management: real-time diagnostics of faulty situations in a communication network, and tactical battlefield situation command and control.

7709A-16, Session 6

Using gaming engines and editors to construct simulations of fusion algorithms for situation management

L. M. Lewis, Southern New Hampshire Univ. (United States); N. DiStasio, Altusys Corp. (United States)

It this paper we discuss issues in testing various cognitive fusion algorithms for situation management. We provide a proof-of-principle discussion and demo showing how gaming technologies and platforms could be used to devise and test various fusion algorithms, including input, processing, and output, and we look at how the proof-of-principle could lead to more advanced test beds and methods for high-level fusion in support of situation management. We develop four simple fusion scenarios and one more complex scenario in which a simple rule-based system is scripted to govern the behavior of battlespace entities.

7709A-17, Session 6

Do you see what I hear? Experiments in multi-channel sound and 3D visualization for network monitoring

D. L. Hall, M. Ballora, The Pennsylvania State Univ. (United States)

Detection of intrusions is a continuing problem in network security. Due to the large volumes of data recorded in web server logs, analysis is typically forensic, taking place only after a problem has occurred. This paper describes a novel method of representing web log information through multi-channel sound, while simultaneously visualizing network activity using a 3-D immersive environment. We are exploring the detection of intrusion signatures and patterns utilizing human aural and visual pattern recognition ability to detect intrusions as they occur.

The paper will present examples of these novel visualizations and sonifications , wherein IP addresses and return codes are mapped to an informative and unobtrusive listening environment to act as a situational sound track and visual animation of web traffic. Initial experiments with human subjects will be described.

Web log data is parsed and formatted using Python, then read as a data array by the synthesis language SuperCollider (www.audiosynth. org), where it is rendered as a multi-track sonification. This approach is applicable both for the study of pre-existing data sets and in monitoring Web traffic in real time. An octaphonic rendering system allows geographic information to be realized along with the components of IP addresses and additional annotations for return codes. Users can interact with the data, speeding or slowing the speed of representation (for pre-existing data sets) or "mixing" sound components to optimize intelligibility. A corresponding visualization allows users to split monitoring activities between the eyes and ears, allowing maximum flexibility for tracking suspicious activity.

7709A-18, Session 6

Smart on-board diagnostic decision trees for quantitative aviation equipments and safety procedures validation

A. H. Ali, G. Markarian, Lancaster Univ. (United Kingdom); A. Tarter, Ultra Electronics Ltd. (United Kingdom); R. Koelle, European Organisation for the Safety of Air Navigation (Belgium)

To compensate for errors that equipments may encounter during flight-time, modern aircrafts are fitted with redundant systems that co-measure some quantity, and then the value of the measurements is decided based on majority rule. However, majority rule might fail if the cause of the malfunctioning is global in such a way as to affect the other redundant systems that are concurrently working out the same measurement. In this paper, we are proposing a validating system that uses as independent as possible ways of calculating the states of an aircraft to serve as evidence node in a diagnostic decision tree and thereby walking through an event of reading anomaly up to its causes.

The proposed network can detect and identify a malfunctioning equipment when a difference between the primary, redundant, and/or the mathematically calculated quantity exceeds a tolerance threshold. The network could also be configured to read BADA performance tables (.ptf) for a given aircraft type and use these as lookup table to validate the aircraft flight data, hence raising the degree of belief in the condition of a situation. Since BADA provide recommendations for reduced threshold operation, adapting to those recommendations would greatly benefit operators in saving fuel, and maintenance as their pilots comply with recommended speed, ROCD, and so on.

7709A-19, Session 6

Twitter Web-service for soft agent situation reporting in persistent surveillance systems

H. R. Rababaah, A. H. Shirkhodaie, Tennessee State Univ. (United States)

Surveillance is the process of monitoring targets behavior, such as humans, objects, processes or phenomena via a network of single/multi-modality sensors (digital cameras, infrared cameras, acoustic, radar, seismic, laser, etc.), where these behaviors are tested against predefined norms of patterns and trends. The main goal of persistent surveillance is to be able to detect, characterize, track and classify events of interest and disseminate their relative information over a network of soft and hard agents in an effective and efficient way to enhance situation awareness in real time. Typical challenges in the data/information reporting and propagation over a network include the challenge of how rapidly an agent can describe an event and share it with other agents on the network and report it to a data/information fusion center. These requirements

are crucial for a complete, effective, efficient and successful operation of such systems. This paper presents a new web-service architecture based on twitter social network technology for soft agent situation reporting. The driving inspiration of this new approach is the concept of "Fast Utilization of Sensory Information Over Network", called FUSION©, which is an opportunistic concept designed to facilitate adaptive fusion schemes supporting situational awareness. The system provides situation assessment scheme that is intuitive, efficient, effective, interactive, and compact. The efficiency and effectiveness of the system was tested based on experimental scenarios including human and vehicle targets exhibiting various normal and suspicious behaviors in a monitored indoor and out door environments. The events of interest in the experimental scenarios included violent vehicle movement and speed, sneaky behavior of human targets, suspicious movement and speed of human intruders, restricted zone violation, picking up or dropping an object etc. The analysis of experimental scenarios strongly supported the validity, reliability, efficiency and effectiveness of the new proposed framework and inspired further future works in various potential applications such as social and industrial applications. Finally, this paper presents integration of twitter-based situation reporting system with a previously developed Energy Logic fusion engine at Tennessee State University to aggregate and fuse information from multi-human agents to further enhance dynamic situation awareness leading to more reliable decision making.

7709A-20, Session 7

Situational awareness and mission risk in computer networks

A. E. Khalili, B. Michalk, L. Gilbert, L. Alford, 21st Century Technologies, Inc. (United States)

Situational awareness and mission risk in computer networks (abstract)

In most organizations, IT infrastructure exists to support the organization's mission. Risks posed to this mission include the threat of cyber attacks. Current network security research focuses on the threat of cyber attacks to the organization's IT infrastructure; however, the risks to the overall mission are rarely analyzed or formalized. For instance, in applied network security, this connection of IT infrastructure to the organization's mission is often neglected or carried out ad-hoc. Our network situation awareness and mission risk management work bridges this gap and introduces analyses and formalisms and to help organizations understand the mission risks they face from cyber attacks.

Modeling an organization's mission vulnerability to cyber attacks requires a description of the IT infrastructure (network model), the organization mission (business model), and how the mission relies on IT resources (correlation model). With this information, proper analysis can show which cyber resources are of tactical importance in a cyber attack, i.e., controlling them enables a large range of cyber attacks. Such analysis also reveals which IT resources contribute to the organization's mission, i.e., lack of control over them gravely affects the mission. These results can then be used to formulate IT security strategies and explore their trade-offs, which leads to better incident response. This paper presents our methodology for encoding IT infrastructure, organization mission and correlations, our analysis framework, as well as initial experimental results and conclusions.

7709A-22, Session 8

Real-time access of large volume imagery through low-bandwidth links

J. Phillips, K. Grohs, B. V. Brower, L. Kelly, L. Carlisle, M. F. Pellechia, ITT Corp. (United States)

Providing current, time-sensitive imagery and geospatial information to deployed tactical military forces or first responders continues to be a challenge. This challenge is compounded through rapid increases in sensor collection volumes, both with larger arrays and higher temporal capture rates. Focusing on the needs of these military forces and

first responders, ITT developed a system called AGILE Access as an innovative approach based on standards off-the-shelf techniques to solving this problem. The AGILE Access system is based on commercial software called Image Access Solutions (IAS) and incorporates standard JPEG 2000 processing. Our solution system is implemented in an accredited, deployable form, incorporating a suite of components, including an image database, a web-based search and discovery tool, and several software tools that act in concert to process, store, and disseminate imagery from airborne systems and commercial satellites. Currently, this solution is operational within the U.S. Government tactical infrastructure and supports disadvantaged imagery users in the field. This paper presents the features and benefits of this system to disadvantaged users as demonstrated in real-world operational environments.

7709A-23, Session 8

Value-of-information middleware for autonomic querying of distributed dynamic sensor databases

S. R. Sukumar, M. Shankar, Oak Ridge National Lab. (United States)

We present a framework to address two challenges emerging in sensor databases. (1) How should we design a middleware software architecture that learns from existing query definitions to motivate, hypothesize and intelligently execute future queries? (2) How to implement situation-adaptive (autonomous) software queries in real-time by incorporating utility of the streaming sensor information?

Let us consider a powerful motivating scenario, where an intelligence analyst) receives in excess of thousands of reports per hour (dozens per second). In a war situation, it is a very small subset of these reports that holds the key to victory, while most of the reports may only contribute to wasted time by delaying a critical decision. In such an unmanageable flow and volume of information, our research goal is to design a framework that enables the analyst to quickly exploit such information to gain victory by implementing autonomy into the information flow-control schema.

If the analyst spends most of his/her time in fetching data that is not providing the strategic edge of intelligence or the database is bogged down by queued up queries, we have to think about a change in querying strategy in complete contrast to existing crawl-index-search paradigms. We propose to send software to the data, and return just the information that is needed. That is why not send 50KB of software to 1GB of data, rather than the other way around? The value-of-information metrics framework provides the basis to enable a paradigm shift in sensor database querying constantly considering success and timeliness.

7709A-24, Session 8

Multivariable cluster analysis in a manufacturing environment for real-time situation awareness

M. Blowers, C. Salisbury, Air Force Research Lab. (United States)

The overall operation and internal complexity of industrial processes may be represented in terms of clusters of multidimensional points which describe the process states. The value in each point dimension represents a measured variable, or sensor reading, from the multiple pieces of machinery in the industrial system. The clusters formed from these various sensor readings have been found to be indicative of process upsets which cause machine failures. This research shows how a novel clustering method may be used to warn operators when corrective action may need to be taken.

7709A-25, Session 8

Decentralized approach for aggregating data

S. Okamoto, K. Sycara, Carnegie Mellon Univ. (United States)

Sensor networks and multi-robot systems must commonly aggregate data from groups of nodes using an ad hoc network. For example, tracking an object in a sensor network often requires fusing data streams from multiple sensors, while a commander's situational awareness in future battlefield environments requires access to status information from assets under his or her command. This aggregation is usually done in a single aggregator node that must receive all of the data. Transmitting data in these networks is often costly (due to limited battery power or risk of enemy detection) and nodes must balance the costs with the benefits of data aggregation. Therefore, the optimal selection of which node will be the data aggregator is an important issue.

We propose and examine token-based algorithms for discovering and selecting suitable nodes for data aggregation in a decentralized manner. In these approaches the nodes pass messages (tokens) that encapsulate aggregation responsibilities and contain both solution and control information. We examine cases of both cooperative and self-interested nodes and the algorithms using simulation to analyze the trade off between the discovery cost (communication cost of finding a solution) and the aggregation cost (the cost of the solution).

Conference 7709B: Visual Analytics for Homeland Defense and Security II

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Visual Analytics for Homeland Defense and Security II

7709B-26, Session 9

Visual analytics: a tutorial

W. J. Tolone, W. Ribarsky, The Univ. of North Carolina at Charlotte (United States)

No abstract available

7709B-27, Session 10

VAP/VAT: video analytics platform and test bed for testing and deploying video analytics in operations

D. O. Gorodnichy, National Research Council Canada (Canada)

For a federal agency that deploys thousands of video surveillance cameras, and collects thousands of hours of video daily, Video Analytics (VA) can be a savior. Deploying Video Analytics by agencies in operational environments however is extremely challenging.

This paper describes the problems faced by federal agencies in deploying VA and present a methodological approach developed with the Video Surveillance and Biometrics (VSB) Section that has been recently formed within the Laboratory & Scientific Services Directorate (LSSD) of the Canada Border Services Agency (CBSA) to resolve these problems. The Video Analytics Platform (VAP) developed by the VSB allows integration of the third party VA codes into existing video surveillance infrastructure. It additionally allows to conduct an unbiased performance evaluation of the cameras and VA modules through the Video Analytic Test-bed (VAT).

7709B-28, Session 10

Video surveillance: Who meets whom, when, and where?

U. E. Jäger, D. N. Willersinn, Fraunhofer-Institut für Informations- und Datenverarbeitung (Germany)

Unveiling unusual or hostile behavior by observing manifold moving persons in a crowd is a challenging if not unsolvable task for human operators, especially when sitting in front of monitors for hours. We propose an automatic alarming system that can assist a human operator. It is based on a processing chain consisting of (1) object tracking, (2) event detection,(3)data retrieval and (4)displaying the relevant video part overlaid by highlighted regions of interest.

In this paper we focus on the event detection stage of the processing chain mentioned above. The selected event of interest is the encounter of people. Although being based on a rather simple calculation, this kind of trajectory analysis has great practical importance because it paves the way to answer the question "who meets whom, when and where". This, in turn, forms the basis to detect potential situations where e.g. money, weapons, drugs etc. are handed over from one person to another in crowded environments like railway stations, airports or busy streets and places.

The input to the trajectory analysis comes from a video-based tracking system being able to track multiple individuals within a crowd in real-time. From this we calculate the inter-trajectory distances between all persons on a frame-to-frame basis. After selecting those distances small enough that people can meet, we output frame number, the person's IDs from the tracker and the pixel coordinates of the meeting position. Using this information, a follow-up system may retrieve the corresponding part of the recorded video image sequence and finally may replay it with a highlighted region of interest that attracts the operator's attention for further visual analysis.

7709B-29, Session 10

Interactive change detection

R. B. Porter, N. R. Harvey, J. Theiler, Los Alamos National Lab. (United States)

An important intelligence task in geo-spatial image analysis is to characterize unknown or unexpected changes that occur over time. These changes are typically rare and ill-defined, but given enough time and resources, a human operator "would know it, if they see it". We address this difficult detection problem as an interactive search task, and describe a machine learning system which improves the efficiency of the search using relevance feedback and the accumulated history of human-computer interactions.

7709B-30, Session 11

Visual strategies for enhancing user perception of task relationships in emergency operations centers

S. Dudzic, A. Godwin, R. Kilgore, Charles River Analytics, Inc. (United States)

In time-sensitive environments, such as DHS emergency operations centers (EOCs), it is imperative for decision makers to rapidly understand and address key logical relationships that exist between critical tasks, entities, and events, even as conditions fluctuate. These relationships often have important temporal characteristics, such as processes that must occur simultaneously in a given location (e.g., coordinating the arrival of firefighters and air support to the same location at a wildfire) or tasks that must be completed before others can be started (e.g., busses must be transported to an area before an evacuation process can begin). Traditional temporal displays, such as mission timelines, typically reveal only rudimentary event details, such as nominal event start and end times, and fail to support user understanding of and reasoning about critical constraints and relationships.

We have developed several design strategies for the enhancement of temporal data displays to explicitly and intuitively convey critical event relationships to decision makers. In this paper, we detail these strategies and describe the evaluation efforts undertaken to assess their usability and effectiveness to support decision making tasks. We present a case study in which we applied our visual enhancements to a timeline display, improving the perception of logical relationships among events in a Master Scenario Event List (MSEL). These methods reduce the cognitive workload of decision makers and improve the efficacy of identification, maintenance, and consideration of these relationships, leading to better decisions in less time.

7709B-31, Session 11

A linked feature space approach to exploring lidar data

L. Harrison, T. Butkiewicz, X. Wang, W. Ribarsky, R. Chang, The Univ. of North Carolina at Charlotte (United States)

A typical approach to exploring LIDAR datasets is to extract features

using pre-defined segmentation algorithms. However, this approach only provides a limited set of features that users can investigate. To expand and represent the rich information inside the LIDAR data, we introduce a linked feature space concept that allows users to make regular, conjunctive, and disjunctive discoveries in non-uniform LIDAR data by interacting with multidimensional transfer functions. We achieve this by providing interactions for creating multiple scatterplots of varying axes, establishing chains of plots based on selection domains, linking plots using logical operators, and viewing selected brushing results in both a 3D view and selected scatterplots. Our highly interactive approach to visualizing LIDAR feature spaces facilitates the users' ability to explore, identify, and understand data features in a novel way. Our approach for exploring LIDAR data can directly lead to better understanding of historical LIDAR datasets, and increase the turnaround time and quality of results from time-critical LIDAR collections after urban disasters or on the battlefield.

7709B-32, Session 11

Some aspects of the geospatial reality perception in human stereopsis-based defense display systems

E. Levin, A. V. Sergeyev, Michigan Technological Univ. (United States)

Intelligence analyst deals with the vast amount of geospatial data obtained from different aerial, satellite and terrestrial (including UAV) sensor platforms. Proper visual representation of this imagery defines convenient perception and finally quality of the targets and other objects interpretation on that fused and complex geospatial data. Since human ability to recognize targets prevails and complements automated target recognition capabilities, research on optimization of sensor data representation has a great impact on decision support systems. In this work we describe multidisciplinary research concentrated on the stereoscopic presentation of geospatial imagery data obtained from various sensors. Source data being different in scale, texture, geometry and content cannot be effectively processed using conventional image processing technique simultaneously. However, human eye-brain system allows subjects to fuse incoherent data and percept as a stereoscopic model. Virtual reality experimental set, based on head-mounted display was designed to efficiently superimpose incoherent images for comfortable stereoscopic perception. Research with experienced and non-experienced human subjects indicates that interpretability of certain targets types increases drastically with stereoscopic perception. One of the most interesting findings is that source geospatial imaging does not have be pre-processed or enhanced for being in the experiments described. In this paper we outline our findings in qauntative estimations of geospatial objects interpretability based on experimental data sets deployed.

7709B-33, Session 11

Semi-automated processing and routing within indoor structures for emergency response applications

J. Liu, K. Lyons, K. R. Subramanian, W. Ribarsky, The Univ. of North Carolina at Charlotte (United States)

In this work, we propose new automation tools to process 2D building geometry data, for effective communication and timely response to critical events in commercial buildings. Given the scale and complexity of commercial buildings, robust visually rich tools are needed during an emergency. Starting from CAD building files, our data processing pipeline consists of three major components, (1) adjacency graph construction, representing spatial relationships within a building (between hallways, offices, stairways, elevators), (2) identification of elements involved in evacuation routes (hallways, stairways), (3) 3D building network construction, by connecting the floor elements via stairways

and elevators. We have used these tools to process a cluster of five academic buildings. Our automation tools (despite some needed manual processing) show a significant advantage over manual processing (a few minutes vs. 2-4 hours). Designed as a client-server model, our system supports analytical capabilities to determine dynamic routing within a building under constraints(parts of the building blocked during emergencies, for instance). Visualization capabilities are provided for easy interaction with the system, on both desktop (command post) stations as well as mobile hand-held devices, simulating a command post-responder scenario.

7709B-34, Session 12

Critical infrastructure recovery system using recommendation framework: a user study

O. Pala, D. Wilson, The Univ. of North Carolina at Charlotte (United States)

Critical infrastructure systems provide for many basic needs of the general population as well as private and government entities. An outage in parts of a network might have a cascading effect on other networks, and this can escalate so that public function can be seriously disrupted. As a result, there is a significant need to improving Critical Infrastructure support and analysis tools in order to prevent and effectively recover from Critical Infrastructure failures. Our research is developing innovative approaches to modeling critical infrastructures in order to support decision making during reconstitution efforts in response to infrastructure disruptions. By modeling the impact of infrastructure elements, both within and across infrastructures, we can recommend focus areas for reconstitution resources in the context of current goals. This paper reports improvements and updates on previously published GIS modeling environment for decision support in critical infrastructure reconstitution. In particular, we report on a fully functional system that takes multiple infrastructures into account as well as results of our interviews with area experts based on their experience with the system.

7709B-35, Session 12

Evaluation of current visualization tools for cyber security

J. T. Langton, VisiTrend, LLC (United States)

Visualization tools for cyber security lag far behind current research in information visualization. Cyber security data sets are notoriously large, yet many of the tools on the popular DAVIX live CD use 3D techniques and parallel coordinates which result in severe obfuscation from overlapping glyphs and lines. For instance, InetVis uses a 3D scatter plot to display network traffic. On even a small network, this can easily result in a solid cube where data points on the inside are completely occluded. Van Wijk has researched these issues in 3D displays (1999). Fua, Ward, and Rundensteiner have proposed methods to declutter parallel coordinates when used with large data sets (1999). However, publications and tools within the cyber security domain seem to be repeating this and other research that has already been performed in the visualization community. Effective cyber visualization must address data sets that are both large and multidimensional and integrate streaming data, application logs, and different data semantics and formats. In this paper we evaluate some of the most commonly referenced visualization tools for cyber security. For each tool, we present a case study and analytical review that references related research on each of the methods it employs. We also provide recommendations based on current research and enumerate challenges and requirements for future tools.

7709B-36, Session 12

Visualization for cyber security command and control

J. T. Langton, VisiTrend, LLC (United States)

Dr. Lani Kass, director of the Air Force Cyberspace Task Force, has noted that cyberspace superiority is a prerequisite for effective operations in all other war fighting domains (Lopez, 2006). To achieve and maintain cyberspace superiority, there is a need for effective Command and Control (C2) tools to observe, plan, execute, and understand the cyber battlespace and potential effects of cyber operations. Visualization has been a key enabler of C2, but traditional methods that focus on geospatial orientation are insufficient for cyber operations where actions and effects may have no physical correlate. At the same time, kinetic operations depend on cyberspace for communications and delivery of mission critical information. It is therefore imperative that commanders are provided methods to visualize and correlate not only relationships between cyber events but also how they affect and are affected by kinetic operations.

A key challenge to cyber C2 visualization and correlation is the complexity of relevant data: it is immense and multidimensional, includes streaming and log data, and comes from a diverse set of applications and devices with different protocols and formats. New methods must support cyber situation awareness and provide decision makers information on a) the current state of the cyber battlespace, b) enemy and friendly capabilities and vulnerabilities, c) correlations between cyber events, and c) potential effects of alternative courses of action within cyberspace. In this paper we present requirements and designs for a Visualization for Integrated Cyber Command and Control (VIC3) system.

7709B-37, Session 12

Dynamic 3D visual analytic tools: a method for maintaining situational awareness during high tempo war fighting or mass casualty operations

T. E. Lizotte, Pivotal Development Co. LLC (United States) and Lizotte Tactical Development, LLC (United States)

Maintaining Situational Awareness (SA) is crucial to the success of high tempo operations, such as war fighting and mass casualty events (bioterrorism, natural disasters). Modern computer and software applications attempt to provide command and control manager's situational awareness via the collection, integration, interrogation and display of vast amounts of analytic data in real-time from a multitude of data sources and formats. At what point does the data volume and displays begin to erode the hierarchical distributive intelligence, command and control structure of the operation taking place? In many cases, people tasked with making decisions, have insufficient experience in SA of high tempo operations and become overwhelmed easily as vast amounts of data begin to be displayed in real-time as an operation unfolds. In these situations, where data is plentiful and the relevance of the data changes rapidly, there is a chance for individuals to target fixate on those data sources they are most familiar. If these individuals fall into this type of pitfall, they will exclude other data that might be just as important to the success of the operation. To counter these issues, it is important that the computer and software applications provide a means for prompting its users to take notice of adverse conditions or trends that are critical to the operation. This paper will discuss a new method of displaying data called a Crisis View , that monitors critical variables that are dynamically changing and allows preset thresholds to be created to prompt the user when decisions need to be made and when adverse or positive trends are detected. The new method will be explained in basic terms, with examples of its attributes and how it can be implemented.

Conference 7710: Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications 2010

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7710-01, Session 1

Capturing dynamics on multiple time scales: a multilevel fusion approach for cluttered electromagnetic data

S. P. Brumby, K. L. Myers, N. H. Pawley, Los Alamos National Lab. (United States)

Many problems in electromagnetic signal analysis exhibit dynamics on a wide range of time scales. Further, these dynamics may involve both continuous source generation processes and discrete source mode dynamics. These rich temporal characteristics can present challenges for standard modeling approaches, particularly in the presence of nonstationary noise and background sources. Here we demonstrate a hybrid algorithm designed to capture the dynamic behavior at all relevant time scales while remaining robust to clutter and noise at each time scale. We draw from techniques of adaptive feature extraction, statistical machine learning, continuous state space modeling, and discrete process modeling to construct our hybrid algorithm.

We will describe our hybrid algorithm and present results applying it to a simulated dataset based on an example radio beacon identification problem: civilian air traffic control (ATC). This application illustrates the multi-scale complexity of the problems we wish to address. We consider a multi-mode ATC radar emitter operating against a cluttered background of radars and continuous-wave (CW) communications signals (radios, TV broadcasts). Our goals are to find a compact representation of the radio frequency measurements, identify which pulses were emitted by the target source, and determine the mode of the source.

7710-02, Session 1

Approaches to information fusion with spatiotemporal aspects for standoff and other biodefense information sources

J. J. Braun, A. Hess, Y. Glina, E. C. Wack, T. J. Dasey, MIT Lincoln Lab. (United States); R. M. Mays, J. Strawbridge, JBSDS, Joint Product Manager, Biological Detection Systems (United States)

Aerosolized biological attack detection is one of the challenging problems in biodefense. Relevant sensing technologies include standoff sensors that detect biological agent clouds remotely, and point sensors that detect biological agent presence at their specific locations. Standoff sensing offers potential advantages of earlier warning and increased coverage. However, reaching the desired detection and false-alarm performance can be more challenging with standoff than with point sensors. Fusing information from multiple standoff sensors and other relevant information sources is a promising path for addressing that challenge.

This paper discusses some of the techniques developed at MIT Lincoln Laboratory for information fusion of LIDAR (Light Detection and Ranging) biological standoff, meteorology, point sensors, and potentially other biodefense information sources. The approach referred to as Spatiotemporal Coherence (STC) fusion includes phenomenology aspects and approximate uncertainty measures for information corroboration quantification. While STC includes adaptive provisions, it is not a machine-learning approach in a traditional sense. A supervised machine-learning approach was developed as well. Computational experiments involved ground-truth data generated from measurements and by simulations, and the techniques developed for ground-truth generation are also outlined in the paper.

Results of the computational experiments indicate that STC and the supervised learning approach both enable significant false-alarm rate reduction. The two approaches are discussed, and their respective advantages and tradeoffs are examined. The results include efficacy measures that focus explicitly on the fusion algorithms' effectiveness. The techniques developed in this effort are promising for fusion of standoff and other biodefense information sources.

7710-03, Session 1

Classification of terrain using multi-resolution satellite/aerial imagery and LIDAR data

A. M. Thomas, B. R. Kocher, Georgia Institute of Technology (United States)

Unsupervised spectral classification of terrain based on multi-spectral imagery distinguishes gross features and terrain types but is of insufficient resolution to effectively classify individual buildings or other smaller features, particularly in urban regions. Several methods of improving classification accuracy and resolution via data fusion are explored. Texturally segmented high resolution satellite and aerial imagery is used to enhance the resolution/detail of the spectral classification. High resolution LiDAR data is also used to augment the spectral data as an additional band to improve resolution/accuracy. Digital elevation information, texture information, and spectral data are all combined into a single dataset and different clustering algorithms are used on the raster information and compared with clusters of spectral data alone. Long term goals of the work are to find efficient and effective methods of combining different data sets of varying resolution from different sources into a single dataset for analysis to improve data and classification resolution and accuracy.

7710-04, Session 1

Data fusion and classification using a hybrid intrinsic cellular inference network

R. Woodley, B. Walenz, 21st Century Systems, Inc. (United States); D. C. Wunsch II, Missouri Univ. of Science and Technology (United States)

Hybrid Intrinsic Cellular Inference Network (HICIN) is intended to provide JDL fusion level 3 support to battlespace decision support applications. We have developed an automatic method of generating hypotheses for an entity-attribute classifier. The capability and effectiveness of a domain specific ontology was used to generate automatic categories for data classification. Heterogeneous data is clustered using an Adaptive Resonance Theory (ART) inference engine on a sample (unclassified) data set. The data set is the Lahman baseball database. The actual data is immaterial to the architecture, however, parallels in the data can be easily drawn (i.e., "Team" maps to organization, "Runs scored/allowed" to Measure of organization performance (positive/negative), "Payroll" to organization resources, etc.). Results show that HICIN classifiers are able to create known inferences from the heterogonous data. These inferences are not explicitly stated in the ontological description of the domain and are strictly data driven. HICIN uses a data uncertainty handling structure to reduce errors in the classification. The uncertainty handling is based on subjective logic using belief mass tuples. The belief mass allows evidence from multiple sources to be mathematically combined to increase or discount an assertion from the classifier. While this feature is limited with the baseball data, in military operations (Command and

Control (C2) and Decision Support Systems (DSS)) the ability to reduce uncertainty will be vital in the data fusion operation. Metrics for measures for improved data fusion and decision support performance of HICIN for enhancing capabilities in battlespace C2 and DSS operations were developed.

7710-05, Session 2

Fusion of ESM reports through Dempster-Shafer and Dezert-Smarandache theories

P. Valin, Defence Research and Development Canada (Canada); P. Djiknavorian, Univ. Laval (Canada); E. Bosse, Defence Research and Development Canada (Canada); D. Grenier, Univ. Laval (Canada)

We address the problem of fusing Electromagnetic Support Measures reports by two evidential reasoning schemes, namely Dempster-Shafer theory and Dezert-Smarandache theory. These schemes provide results in different frames of discernment (with different cardinalities), but are able to fuse realistic ESM data. We discuss their advantages and disadvantages under varying conditions of sensor data certainty and fusion reliability, the latter coming from errors in the association process. A thresholded version of Dempster-Shafer theory is fine-tuned for performance across a wide range of values for certainty and reliability, allowing designers who wish to use this method to assess the expected performance. The results are presented first for typical scenarios, and secondly for Monte-Carlo studies of scenarios under varying sensor certainty and fusion reliability. The results are complex non-linear functions, but for which clear trends can nevertheless be extracted. A compromise has to be achieved between stability under occasional miss-associations, and latency under a real change of allegiance. The alternative way of reporting results through Dezert-Smarandache theory is studied under similar conditions, and shown to provide good results, which are however more dependent on the unreliability, and slightly less stable. In this case however, the frame of discernment is larger, and permits additional interpretations (Suspect, and Assumed Friend), which are outside the scope of Dempster-Shafer (which reasons only over Friend, Neutral and Hostile).

7710-06, Session 2

Level 0-2 fusion model for ATR using fuzzy logic

C. F. Hester, K. K. Dobson, U.S. Army Aviation and Missile Research, Development and Engineering Ctr. (United States)

The JDL model for fusion provides a structure for fusion of multispectral data at all levels. Fused data provides improved performance in Automatic Target Recognition(ATR). Critical to the overall fusion performance, however, is the low level(0-2) fusion of sensory and context information. Loss of information must be avoided at this level, but complexity must be reduced. A model is presented that uses fuzzy sets to form entities and capture the information needed for target recognition. Examples using multispectral imagery will be presented.

7710-07, Session 2

Protection of scanned documents with digital watermarking based on the 2D complex Hadamard transform

M. G. Milanova, Univ. of Arkansas at Little Rock (United States); R. Kountchev, Technical Univ. of Sofia (Bulgaria); V. Todorov, R. Kountcheva, T&K Engineering Co. (Bulgaria)

This paper presents a new approach for documents' content protection, based on two algorithms for image watermarking, based on the 2D complex Hadamard transform (CHT). The first algorithm allows for resistant WM insertion through phase modulation of the complex-conjugated CHT coefficients with the WM elements. The second algorithm allows for fragile watermarking, by means of amplitude modulation of the real CHT coefficients. Depending on the application, one of the two algorithms should be chosen: against the attacks for WM removal or for the detection of unauthorized document editing. The paper presents the two methods. The first algorithm ensures reliable extraction of the inserted WM, high resistance against attacks (for example, after JPEG compression) and very low WM noticeability in the processed image. The information capacity of the resistant WM (in bits) can be as much as the number of ¾ of the pixels in the image, and for the WM detection is needed a simple private/public only and the original image is not used. For the second algorithm (fragile WM insertion), the use of the original images is required for the successful WM extraction from the amplitude-modulated real CHT coefficients of the processed documents. An advantage of the algorithm is that owning the decoding software does not permit WM extraction without having a password. Furthermore, any unauthorized editing makes the WM restoration impossible.

Experimental results of the algorithms modeling are presented in this paper confirming the efficiency of the two algorithms.

7710-08, Session 2

Multi-layered context impact modulation for enhanced focus of attention of situation awareness in persistent surveillance systems

A. H. Shirkhodaie, H. R. Rababaah, Tennessee State Univ. (United States)

Persistent surveillance systems are one of the highly-motivated contemporary technologies that have very important applications especially: homeland security, battlefield intelligence, boarder monitoring, facility guarding and other civilian applications. Persistent surveillance systems require a complex integrated framework of layered sensor networks, human agents, efficient and effective communication protocols, data and information fusion models, intelligent cognition schemes, data visualization, intelligent reasoning methods, human computer interfacing and situation awareness techniques. Although, much work has been done in the area of persistent surveillance, there still exist some crucial requirements that need to be addressed for a complete, effective, efficient and successful operation of such systems. Among these requirements is context impact modulation (CIM) of the events. This paper presents an experimental integration of a context impact modulation concept for a sensor networked persistent surveillance system. The paper presents a multi-layer CIM approach including: spatial, temporal, sensor reliability, human presence, and environmental layers. To enhance the focus of attention at the common operation picture (COP) a fusion model is presented to combine all the impacts from the different layers onto one unified modulated map. The new proposed system was tested using real world scenarios that included human and vehicle targets exhibiting various normal and suspicious behaviors in a monitored indoor and out door environments. The events of interest in the experimental scenarios included violent vehicle movement and speed, sneaky behavior of human targets, suspicious movement and speed of human intruders, restricted zone violation, picking up or dropping an object etc. The analysis of experimental scenarios strongly supported the validity, reliability, efficiency and effectiveness of the new proposed framework and inspired further future works in various potential applications such as social and industrial applications. Finally, this paper presents the integration of CIM with a previously developed Energy Logic fusion engine at the Tennessee State University to aggregate and fuse information that improve dynamic situation awareness leading to more reliable decision making.

7710-09, Session 3

Global evaluation of focussed Bayesian fusion

J. Sander, Karlsruhe Institute of Technology (Germany); M. Heizmann, Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Germany); I. Goussev, Karlsruhe Institute of Technology (Germany); J. Beyerer, Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (Germany) and Karlsruhe Institute of Technology (Germany)

In most real world examples, the application of Bayesian fusion methods is critical or even impossible because of high storage and computational costs. Local Bayesian fusion approaches reduce the computational complexity of Bayesian fusion drastically by a concentration of the actual Bayesian fusion task on its probably most task relevant aspects. In this paper, further research results on a special local Bayesian fusion technique called focussed Bayesian fusion are reported. At focussed Bayesian fusion, the actual Bayesian fusion task gets completely restricted to the probably most relevant parts of the range of values of the Properties of Interest. Using a landscape model, we show the practical usefulness of focussed Bayesian fusion in the field of reconnaissance. In the given example, focussed Bayesian fusion is used for the combination of symbolic information from a street map, information from a human observer and different kinds of image information with the aim to detect vehicles in a scene and to determine type, position and driving direction of the vehicles. Here, final decisions are based on local significance considerations and consistency arguments. Generally, the absolute values of focussed probability statements represent upper bounds for their global values. We noted this fact in previous publications. Here, we additionally prove lower bounds which are obtained from the knowledge about the construction of the focussed Bayesian model. Subsequently, the usefulness of the resulting probability interval scheme will be discussed. The global meaning of a focussed Bayesian model will be clarified in a comprehensive manner.

7710-10, Session 3

Detection of security-relevant behavior of two or more persons using a network of LIDAR sensors with highly directional and stationary beams

K. Wenzl, H. Ruser, C. Kargel, Univ. der Bundeswehr München (Germany)

The use of camera-based networks and systems for surveillance purposes can be problematic since personally identifiable information is collected.

For this reason, we develop a surveillance sensor network based on the LIDAR (LIght Detection And Ranging) principle. In order to minimize the system complexity, power consumption and costs, the network topology and LIDAR sensors must be optimized in terms of number of nodes, measurement distance, beamwidth and signal-to-noise-ratio. As a result, a significant portion of the surveillance area is not directly assessed by the sensors which makes it challenging to accurately track even a single target throughout the entire area of surveillance.

In the proposed paper we shall evaluate the performance of an appropriately designed sparse network of infrared LIDAR sensors with highly directional stationary beam patterns to reliably track two or more persons. The tracking of multiple moving targets in the area of surveillance is carried out by applying a Kalman filter approach. To detect persons with suspicious, security-relevant behavior we propose probabilistic methods based upon the estimated target trajectories and dynamics. The tracking and classification performances are derived from simulations and experiments applying commercial laser scanners. Although popular general-purpose laser scanners measure at rather

low scan rates, are rather bulky, heavy, not absolutely noiseless due to the mechanical scanning, and also costly they offer ample experimental flexibility which is highly advantageous at this point of our investigations.

7710-12, Session 3

A copula-based semi-parametric approach for footstep detection using seismic sensor networks

A. Sundaresan, A. Subramanian, P. K. Varshney, Syracuse Univ. (United States)

In this work, we present a novel approach for detection using the theory of copulas. A parallel network of seismic sensors is considered that transmit their raw observations to a fusion center for decision-making. The measurements received at the sensors, any given time instant, are spatially correlated and are characterized by a multivariate distribution. Using the theory of copulas, the sensor observations are completely characterized by a single parametric copula function, which is then used for decision making at the fusion center. Such an approach for detection does not require prior knowledge about the marginal distribution of individual sensor observations and hence is rendered semi-parametric. The parameters of the copula function describing the statistics of the sensor observations are directly estimated from the sensor observations. Using test-bed data, we show that the semi-parametric approach is particularly attractive in the case of indoor seismic data because of the difficulty to fit suitable parametric distributions to the individual sensor observations. The spatial correlation among sensor observations can get manifested in several different and potentially non-linear ways and many families of copula functions have been specified in the literature to address this issue. We also use the test-bed data to determine which copula function best describes the statistics of the seismic data using goodness-of-fit tests and information theoretic metrics. Experimental results using the test-bed data are provided to demonstrate the efficacy of the copula based approach. The performance improvement over other commonly adopted approaches like assumption of conditional independence of sensor observations or assuming the correlated sensor observations to be multivariate Gaussian is also presented.

7710-13, Session 4

Envisioning cognitive robots for future space exploration

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Cognitive robots in the context of space exploration are imagined as a next step from autonomous robots, with enhanced capabilities of model building (both model refinement and total model regeneration), continuous planning/re-planning (traditional or opportunistic, at multiple-levels/domains of mission planning and resource optimization, further refined to path/trajectory planning, agile/efficient sensing - instrument planning, etc) self-diagnostic with potential self-repair, and most elusively and yet core to cognition, being able to overcome the bottleneck of 'understanding' new situations, one aspect of which being recognizing when a situation is normal or abnormal and address it appropriately.

Reasoning involves models, which are built based on information from multiple sources, at different angularities, levels of resolution of space, time, frequency, etc. Information fusion is fundamental to interpretation of the of the sensed data, in planning the operation (path/trajectory, sensing, use of resources), etc..

We overview the main futures of a set of approaches and tools used at NASA/JPL over the years (such as CASPER- planning, DARTS- modelling and simulation, OASIS - science data analysis, etc) and formulate an architecture that combines these in the context of a cognitive robotic system operating in a various scenarios. Examples of scenarios include a single rover mission (scenario of a planetary in-situ laboratory),

multi-robot mission (in the context of a sample return mission involving orbiters, surface systems, etc) and human-robot mission (which involves intelligent collaboration both with astronauts in orbiting spacecraft and astronauts operating on planet surface).

7710-14, Session 4

Cognitive plausible robotics

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There are many approaches to building intelligent robots. Our approach is to use representations, processes, and strategies that humans use embodied on a robotic architecture. We use ACT-R/E (Adaptive Character of Thought-Rational/Embodied), a computational cognitive architecture which excels at providing process descriptions of how people solve different tasks. ACT-R/E (Kennedy et al., 2009; Harrison & Trafton, 2009; Trafton et al., 2006, 2008, 2009) is based on Anderson's ACT-R theory (Anderson, 2007).

Our approach allows advantages from many different perspectives. From a cognitive science point of view, we can explore issues of embodiment, representation, and modeling. From a robotics point of view, we have a robotics architecture based on the system that integrates information better than any other (people) and we are able to facilitate interaction between people and robots because our ACT-R/E system uses similar representations, strategies, and knowledge that people do. From an AI point of view, we are striving toward building a human-level intelligent robotic system.

7710-15, Session 4

Using conceptual spaces to fuse knowledge from heterogeneous robot platforms

Z. Kira, Georgia Institute of Technology (United States)

As robots become more common, it becomes increasingly useful for many applications to use them in teams that sense the world in a distributed manner. In such situations, the robots must communicate and fuse information received from multiple sources. A key challenge for this problem is perceptual heterogeneity, where the sensors, perceptual representations, and training instances used by the robots differ dramatically. In this paper, we use Gärdenfors' conceptual spaces, a geometric representation with strong roots in cognitive science and psychology, in order to represent the appearance of objects and show how the problem of heterogeneity can be intuitively explored by looking at the situation where multiple robots differ in their conceptual spaces at different levels. To bridge low-level sensory differences, we abstract raw sensory data into properties (such as color or texture categories), represented as Gaussian Mixture Models, and demonstrate that this facilitates both individual learning and the fusion of concepts between robots. Concepts (e.g. objects) are represented as a fuzzy mixture of these properties. We then treat the problem where the conceptual spaces of two robots differ and they only share a subset of these properties. In this case, we use joint interaction and statistical metrics to determine which properties are shared. Finally, we show how conceptual spaces can handle the removal of such missing properties when fusing concepts received from different robots. We demonstrate successful fusion of information in a realistic 3D simulation environment consisting of autonomous ground and aerial vehicles performing joint reconnaissance of an outdoor environment.

7710-16, Session 4

Integrating perception and problem solving to predict complex object behaviors

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One of the objectives of Cognitive Robotics is to construct robot systems that can be directed to achieve real-world goals by high-level directions rather than a complex, low-level robot programming. Such a system must have the ability to represent, problem-solve and learn about its environment as well as communicate with other agents. In previous work, we have proposed ADAPT, a Cognitive Architecture that views perception as top-down and goal-oriented, so that perception becomes part of the problem solving process. This approach is linked to a SOAR-based problem-solving and learning framework. In this paper, we focus on the architecture for the perceptive and world modelling components of ADAPT and report on experimental results using this architecture to perceive events in a complex, real-world scenario.

Consider an object, such as a ball, moving in cluttered environment and consider a robot given the objective of intercepting the object. The robot must track the object as it moves and determine how to intercept it. However, in a cluttered environment, it is highly likely the object will collide and rebound from the environment. Tracking can at most handle this on a collision-by-collision basis. In our approach a world modelling system - a 3D game engine - is intimately linked into the visual perception process. Predictions of complex object behavior such as repeated rebounds from the environment are generated from the world modelling system at very high rates and are available as 'imagined' perceptions, directly comparable with actual perceptions.

We present results from this approach using a Pioneer AT3 robot equipped with stereovision to syncronize its visual input with the game engine graphical output, and to use this syncronization to predict and travel to intercept locations for a ball after several rebounds.

7710-17, Session 4

A cognitive approach to classifying perceived behaviors

D. P. Benjamin, Pace Univ. (United States); D. M. Lyons, Fordham Univ. (United States)

This paper describes our work on integrating distributed, concurrent control in a cognitive architecture, and using it to classify perceived behaviors. We are implementing the Robot Schemas (RS) language in Soar.

RS is a CSP-type programming language for robotics, that controls a hierarchy of concurrently executing schemas. The behavior of every RS schema is defined using port automata. This provides precision to the semantics and also a constructive means of reasoning about the behavior and meaning of schemas. Our implementation uses Soar operators to build, instantiate and connect port automata as needed.

Our approach is to use comprehension through generation (similar to NLSoar) to search for ways to construct port automata that model perceived behaviors. The generality of RS permits us to model dynamic, concurrent behaviors. A virtual world (Ogre) is used to test the accuracy of these automata. Soar's chunking mechanism is used to generalize and save these automata. In this way, the robot learns to recognize new behaviors.

7710-18, Session 4

A cognitive robotics system: the Symbolic and Sub-symbolic Robotic Intelligence Control System (SS-RICS)

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The Symbolic and Sub-symbolic Robotic Intelligence Control System (SS-RICS) is intended to be an implementation of robotic control based on computational models of human cognition. Development of SS-RICS has concentrated on the integration of theories within the field of cognitive psychology - primarily theories of knowledge representation and organization. SS-RICS is a hybrid robotics system that allows for a continuum of knowledge that includes both symbolic as well as sub-

symbolic constructs. At this time SS-RICS consists of a production system architecture with declarative memory elements which decay at rates similar to human cognition. The system is capable of using laser data and video imagery to identify salient objects in the environment and then move to the objects. Productions can be executed via voice commands. We have recently implemented Decision Field Theory into the production system to allow for more complex decisions to be considered. For example, this allows SS-RICS to consider and costs, preferences, and values of certain decisions beyond simple IF-THEN decisions of a production system. This will be implemented as a conflict resolution algorithm for complex choices. We have also implemented Simultaneous Localization and Mapping (SLAM) algorithms, path planning, and localization algorithms for navigation. Perception is still a difficult issue and we are using both template based matching and neural networks, especially Adaptive Resonance Theory (ART) nets, for perceptual tasks. ART nets allow for dynamic additions to previously learned data, which is essential for a robotics system.

7710-19, Session 4

Cognitive robotics using vision and mapping systems with Soar

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The Cognitive Robotic System, or CRS, has been developed to use the Soar cognitive architecture for the control of unmanned vehicles and has been tested on two heterogeneous ground robots: a six-legged robot (hexapod) and a wheeled robot. The CRS has been used to demonstrate the applicability of Soar for unmanned vehicles by using a Soar agent to control a robot to navigate to a target location in the presence of a cul-de-sac obstacle. The CRS was able to successfully navigate the cul-de-sac obstacle with only minimal high level perceptual information from the environment and without the use of a map by changing its approach to avoiding obstacles whenever its current approach was unsuccessful. This initial work with the CRS demonstrated that adding more knowledge to a Soar agent in the form of Soar rules and providing it with more information from sensors can lead to a more capable Soar agent and more intelligent robot behavior. The usefulness of Soar for unmanned vehicles is likely to be substantially increased when Soar agents have access to relevant symbolic information about their environment. Therefore, current work on the CRS has focused on the development of computer vision and map generating systems that are capable of generating high level information from the environment that will be useful for reasoning in Soar.

7710-20, Session 5

An orientation-based fusion algorithm for multisensor image fusion

Y. Zheng, Alcorn State Univ. (United States)

Multiscale fusion algorithms (wavelet or pyramid) can usually satisfy multisensory image fusion. However, those algorithms are not ideal to fuse visible images and infrared images whose intensities appear inverted. Therefore, a novel orientation-based fusion algorithm is proposed in this paper to address this problem. First, a set of M×N Gabor wavelet transforms (GWT) are performed with two input images (I_A and I_B). At each frequency band (1, 2, ..., M), the index of maximal GWT magnitude between two images is selected pixel by pixel; and then two index frequencies, H_A and H_B, are calculated as its index accumulation along N orientations, respectively. The final H_A and H_B are the weighted summations through M bands, where the band weights (W_M) are given empirically. Eventually, the fused image is computed as $I\_F = I\_A .* H\_A + I\_B .* H\_B$, where '.*' denotes element-by-element product of two arrays. The orientation-based fusion algorithm can be implemented by either suppressing DC (direct current) or keeping DC in GWT. "Suppressing DC" will result a sharpened fusion, while "keeping DC" will produce a contrast-smooth image. In our experiments, the

following parameters were used, M = 8, N = 16; and W_M = [0.05 0.1 0.175 0.175 0.175 0.175 0.1 0.05] (to emphasize the contributions of middle frequencies). Not only are the fused images of visible and infrared images satisfied, but the fusions of other image sets (e.g., CT + MRI, NIR + IR) are also comparable to the results of multiscale fusion algorithms. The proposed algorithm can be applied to multiple (more than two) image fusion.

7710-21, Session 5

Feature-based orthorectification of aerial and satellite imagery

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When images are taken from sensors that are not bore-sighted, their pixels are seldom explicitly related. Discrepancies occur in the areas of the ground that are sampled by the pixels of each image. Furthermore, these discrepancies are most often non-linear in nature. The conventional approach to addressing this problem is to use DEMs to orthorectify the images thus putting disparate images into a common coordinate frame. Unfortunately, this process introduces non-linear errors into the images through a resampling procedure. Practically stated, the process often distorts large objects, smoothes over objects of low pixel count, and may eliminate the ability to detect subpixel objects. IN order to address this problem, a procedure is considered that detects and describes features in the original imagery. The features from multiple images are then associated with ground locations and with each other using DEM's.

7710-22, Session 5

Long-duration fused feature learning-aided tracking

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Multiple hypothesis tracking (MHT) algorithms solve the report-to-track association problem by accumulating kinematic evidence provided by one or more sensors over time to find likely correlations in the data. MHT technologies have long been applied to such problems as machine vision, automatic target tracking using radar moving target indicator (MTI) for ground, air, and sea vehicles, video object tracking, missile defense, and satellite tracking. However, relying on kinematic information alone to maintain reliable track in a multi-target scenario is problematic due to a plethora of issues such as sensor limitations, obscuration of the targets, or target/confuser proximity. We introduce a new track fusion algorithm, the Long-Term Hypothesis Tree (LTHT) that solves the tracklet-to-tracklet association problem by using signature information. LTHT provides a framework for using arbitrary target signatures such as spectral or shape characteristics to correct errors made by an MHT tracker. The LTHT represents high-level interactions among complex tracks by condensing kinematic track trajectories into a compact representation that can be efficiently maintained over much longer temporal scales than typical MHT trees.

7710-23, Session 5

Dynamic image fusion and observer preference

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Recent developments in image fusion give the user community many options for ways of presenting the imagery to and end-user. Recently, individuals at the US Army Night Vision and Electronic Sensors Directorate have developed an electronic system that allows users

to quickly and efficiently determine optimal image fusion algorithms and color parameters based upon collected imagery and videos from environments that are typical to observers in a military environment. After performing multiple multi-band data collections in a variety of military-like scenarios, different waveband, fusion algorithm, image post-processing, and color choices are presented to observers as an output of the fusion system. The observer preferences will give guidelines as to how specific scenarios should affect the presentation of fused imagery.

7710-24, Session 5

Technical overview of the Sarnoff Acadia II vision processor

G. S. van der Wal, Sarnoff Corp. (United States)

The Sarnoff Acadia II is a powerful multicore System-on-a-Chip that was specifically developed to support advanced imaging applications where system size, weight and/or power are severely constrained. This paper, targeted at vision system software and hardware developers, will present a detailed technical overview of the Acadia II, highlighting its architecture, processing capabilities, memory interfaces and peripheral interfaces. All major subsystems will be covered, including: Vision Preprocessing via Acadia's low power/latency core which provides enhanced Laplacian Pyramid-based fusion with contrast normalization and noise coring, four warping functions, pyramid-based filtering, global motion estimation, support for stereo imaging, and Harris Corner Detection; Application Processing via the MPCore, an integrated set of four 333MHz ARM11 processors, each with a vector floating point coprocessor and 64kByte of Level 1 Cache; SDRAM Interfacing via a 64-bit, 266MHz DDR2 interface supporting up to 2GB of external memory; On-Chip Local RAM, providing the MPCore with low power/latency access to DDR2 data via DMA; Dual-layer AMBA Switch Fabric, providing fast 64-bit connectivity between cores, memory and peripheral devices; and a large Peripheral Interface Suite, including FLASH memory interface, two USB 2.0 ports, five serial ports, three 133MB/sec Link Ports (used for sharing data with FPGAs, other Acadias, etc), three SPI ports, three 108MHz 16 bit video input ports and a 30-bit SXGA/720P video output port. The paper will emphasize the programmability and configurability of the Acadia II, while describing its ability to provide state-of-the-art real-time image processing in an extremely small (29mm x 29mm), power optimized and optimizable package.

7710-25, Session 6

Multisensor data fusion with disparate data sources

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In many instances, sensing tasks are best addressed with multiple sensing modalities. However, fusion of the outputs of disparate sensor systems presents a significant challenge to forming a cohesive sensing system. A discussion of strategies for fusion of disparate sensor data is presented and illustrated with examples of real time and retrospective data fusion for multisensor systems. The first example discussed is a real-time system for situational awareness and the detection of damage control events in ship compartments. The second example is a retrospective data fusion framework for a multisensor system for the detection of buried unexploded ordnance at former bomb and target ranges. A third example is the data fusion analysis for the range test validation system that integrated point and standoff sensors for real-time chemical agent detection.

7710-26, Session 6

Architecture of an over-the-horizon, connected home/office (OCHO) for monitoring ambient environmental, medical, and security conditions at a remote premises via broadband wireless access

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The growing maturity of the standards for broadband and mobile wireless access, e.g., Long Term Evolution (LTE), WiMAX (IEEE 802.16), IEEE 802.11n, etc., together with advances in the development of communication and sensing devices that are compliant with these standards, has enabled the feasibility of remote access to a multi-sensor system that monitors the conditions, collectively termed the situation, of the ambient environment, occupant health, and physical security within a residence or office. The purpose of remote access is to permit management, i.e., assessment and control, of the conditions at the premises by one or more mobile users at a long distance from those premises. The end users for such an over-the-horizon, connected home/office (OCHO) monitoring system are the owner of the premises and other individuals or organizations, contracted by the owner, to mitigate or resolve any out-of-tolerance condition(s) at the premises observed via broadband wireless access. The end users can be mobile as they receive situation reports from the OCHO systems on conditions at the premises via handsets. The handset can be visualized as a smart phone, or its functional equivalent, that is compliant with mobile broadband access standards and enhanced with custom software for the OCHO application. An end user has the option of selecting the level of detail, in other words, the level of situation awareness, displayed as a report for monitored conditions at the premises: (1) the lowest-level report is a list of alerts for the monitored conditions; (2) a more detailed report shows the current values and corresponding tolerance ranges for one or more of the monitored conditions; (3) a complete, in-depth report is display supported by a download of the ambient audio, operational data for monitored devices, images, and/or live video for one or more of the monitored conditions. While relatively narrowband (second-generation or third-generation) mobile wireless access can support continuous requests for OCHO reports (1) and (2), in-depth status reports of Type (3) may contain processed information from all sensed phenomena at the premises and thus could be several hundred megabytes (MB) in length. Type (3) reports can only be delivered on demand to remote end users via a mobile broadband wireless system, e.g., mobile WiMAX or LTE.

The focus of this work is the implementation of the wireless elements that enable the OCHO system coupled with a performance analysis of the resulting mobile-fixed network to estimate metrics, e.g., end-to-end delay and jitter, bandwidth, throughput, etc., that determine the quality of the multisource information fusion displayed in the reports requested by end users. The effect of the metric values determined in the performance analysis on the process of situation management by multiple decision makers is briefly examined.

Data from monitored conditions at the premises are collected and processed by a local system of fixed wireless nodes, each equipped with multiple sensors; each sensor type is designed to measure a specific phenomenon in the environment. Some decision-support actions are automatically triggered by the local system of embedded sensors without intervention by the remote end users. For example, humidity and temperature sensors report their data directly to the heating, ventilation, and air conditioning (HVAC) system that automatically responds to this data by maintaining indoor ambient conditions within ranges set by the end user. Tamper alarms installed at windows and other portals detect any intrusions at the periphery of the premises; the detections automatically trigger activation of wireless high-definition cameras that are able to capture video of the intruders; the video can subsequently be used by remotely located security services or law enforcement to identify the intruders. The medical condition of any patient-occupant within the premises can be observed with existing low-power sensor devices that monitor electrocardiogram (ECG), body temperature, blood glucose, hemoglobin A1c, and other biochemical conditions of the patient, and

then send their data to a control base station for processing to generate health reports. Health reports on patient-occupants may be stored locally at the control station and then, in response to requests from remote end user(s), transferred periodically to a database at a distance from the premises, or, in the case of out-of-tolerance medical emergencies, directly to remote clinicians on call.

The mobile segment of the OCHO system is based on broadband wireless (cellular) access by potentially multiple mobile clients, considered here the end users of the system. Implementation of the mobile segment is made possible with devices such as a MiFi, an acronym for "my Wi-Fi", where Wi-Fi is a trademark of the industry alliance for wireless local area networks (WLANs). A MiFi is a portable broadband wireless device that combines the functions of a modem, router and access point. The internal modem accesses a wireless signal, in this case, from the control base station/access point to the system of fixed wireless nodes at the premises, while the internal router shares that connection among users and devices. A MiFi device can be used to set up an ad-hoc network with a shared Internet connection anywhere with cellular connectivity. The control base station at the premises collects multi-sensor data from the system of fixed wireless nodes and processes the data to information in order to satisfy report requests from the remote end users. Based on the report request received via the mobile broadband wireless connection, the combination of the MiFi and control base station generates and transmits the formatted information for the report via the wireless connection back to the remote end user. The control base station can be considered the hub of the network of fixed wireless multi-sensor nodes. The system of wireless nodes can be viewed as the fixed segment of a femtocell. Femtocells are an alternative method to deliver the benefits of fixed-mobile convergence; a femtocell deployment will avoid the need for a dual-mode handset and works with existing handsets but requires installation of a new access point, e.g, a MiFi device. A wireless access standard, appropriate for data transfers, e.g. Zigbee (IEEE 802.15.4) or IEEE 802.11n, can link the wireless sensors at fixed nodes to the hub, provided there is sufficient bandwidth to support high-definition video streams from wireless cameras. The sensor nodes, control base station, and access point can operate parasitically from existing power sources within the premises, with possible battery backup for all devices in case of power outages. Hence, unlike the design considerations for many wireless sensor networks, energy efficiency is not the primary factor in the implementation.

As stated in preceding comments, while some sensor data may be used to automatically activate local regulation of the conditions at the premises or to activate secondary sensors, the major share of decision-support actions required for situation management of the conditions at the premises originates from situation awareness and assessment by the remote end user(s). The judgment by the owner of the premises, termed the primary end user of the OCHO system, to delegate decision making to other remote end users, deemed experts in the mitigation or resolution of out-of-tolerance conditions at the premises, generates multiple, potentially dissimilar situation assessments based on the cognitive understanding of each end user to information contained in individually requested reports. Dissimilar situation assessments can, in turn, lead to dissonant decisions by the end users in the management of the perceived situation at the premises. Inadvertent outcomes resulting from isolated and uncoordinated actions by end users can be precluded by a coordinated strategy among all remote decision makers for situation management. A situation management strategy must be approved by all designated end users before the start of system operation. Algorithms that implement the strategy prioritize and synchronize end-user responses to any circumstance that may arise at the premises in accordance with mutually approved performance criteria on the collective consequences of all remedial actions. Tradeoffs among alternate situation management strategies for the OCHO system are evaluated to minimize a combination of common performance metrics, e.g., delay in mitigation of alarm conditions, cost of unintended (collateral) physical damages to the premises, measurable deterioration in the medical condition of the patient-occupant beyond normal readings, etc., based on the effects of the collective response by the end users. The proposed evaluation method of the algorithmic representations for alternate situation management strategies leads to coordinated action plans for designated end users, as decision makers, to maintain monitored conditions at the remote home or office within tolerances.

7710-27, Session 6

Application of the JDL data fusion process model for cyber security

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The core of this research is an applied model of data fusion in cyber security domain using the JDL model as a base. This provides the opportunity to leverage the multi-year, enormous investments made by the Department of Defense (DoD) in data fusion applied to military applications such as automated target recognition, threat assessment and situation awareness. For DoD applications, the JDL model represents a standard used for over 15 years, with extensive supporting information related to data fusion sub-processes, algorithms and techniques. The JDL model defines six levels of processing including; (1) source preprocessing, (2) object refinement, (3) situation refinement, (4) threat refinement, (5) process refinement, and (6) cognitive refinement. The model describes the transformation from sensor observations to knowledge representation about an evolving situation or threat condition. In our research, each of the six levels of fusion outlined in JDL is characterized with corresponding examples from network security technologies. Cyber security sensors are described and evaluated as to whether they provide the right types of data for higher levels of inference required by the analyst. Fusion algorithms are also explored, assessing their suitability for assisting in the development of situational awareness and prediction of future actions. This paper concludes with a discussion of the needs of the security analyst in terms of working memory, split attention, cognitive load, development of situational awareness and the technical systems that aid or deter the analyst from developing a mental model of activities on the network.

7710-28, Poster Session

Fast color-transfer-based image fusion method for merging infrared and visible images

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We present a computationally efficient color image fusion algorithm for merging infrared and visible images. At the core of the proposed method is the color transfer technique based on the YCBCR space. The method directly uses the grayscale fused image and the difference signals of the input images to construct the source YCBCR components, then uses the statistical color transfer technique to form a color fused image that takes the target image's color characteristics. Two different strategies, which respectively employ the pixel averaging fusion scheme and the multiresolution fusion scheme as the grayscale image fusion solution, are proposed to fulfill different user needs. The simple strategy using the pixel averaging fusion scheme answers to a need of easy implementation and speed of use. And the complex strategy using the multiresolution fusion scheme answers to the high quality need of the fused products. In addition, we also describe some useful theories about color-transfer-based image fusion. Experimental results show that the proposed color image fusion algorithm can effectively produce a natural appearing "daytime-like" color fused image, and even using the pixel averaging fusion scheme to implement the grayscale fusion can also provide a pleasing result.

7710-29, Poster Session

Implementing real-time imaging systems using the Sarnoff Acadia II vision processor

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Designers of modern vision systems often face the daunting challenge of implementing powerful real-time image processing capabilities in

systems with extreme size, weight and power (SWAP) constraints. Multi-sensor fusion, image stabilization, moving target detection and tracking, and image enhancement - including contrast normalization, dynamic range compression, and noise reduction - are fundamental processing techniques required by vision-based systems such as UAVs, UGVs, intelligent cameras, weapon sights, and night vision goggles - systems that all have very demanding SWAP requirements. Further, the integration of additional sensor data, including GPS and IMU as well as LIDAR and millimeter wave images - is also often required, as is the need to communicate large amounts of processed data to displays, radio links, and data loggers. To meet these demanding requirements while also providing significant general-purpose compute capability, Sarnoff developed the Acadia II, a <4 Watt, 29 by 29 millimeter System-on-a-Chip that combines dedicated stabilization, fusion, and image compression cores with four ARM11 processors, on-chip cache memory, and an abundance of peripheral devices. Acadia II's on-chip peripherals include a 2GB DDR2 port, a 64MB FLASH memory port, two USB 2.0 ports, five serial ports, three 133MB/sec parallel ports, three SPI ports, three 108MHz 14-bit video input ports, and a 30-bit output port supporting image sizes up to 2,048 by 2,048. This paper will describe how to best use the power of the Acadia II as both an all-in-one image processor and as a general purpose computer for performing other critical non-vision tasks, such as flight control and system-to-system communication.